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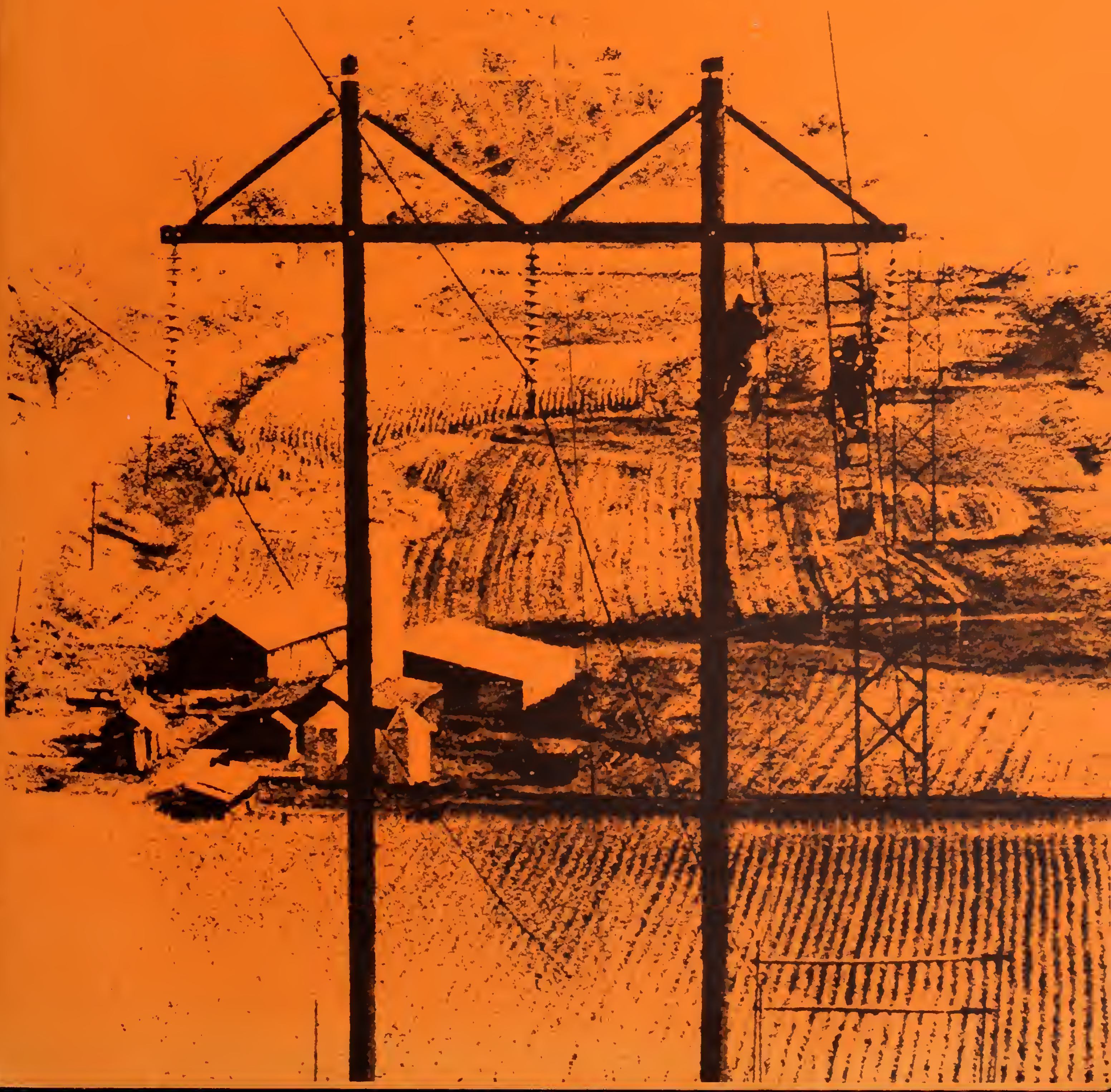
Design Manual for High Voltage Transmission Lines



UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

BULLETIN 1724E-200

SUBJECT: Design Manual for High Voltage Transmission Lines

TO: All Electric Borrowers

EFFECTIVE DATE: Date of Approval

EXPIRATION DATE: Three years from effective date.

OFFICE OF PRIMARY INTEREST: Transmission Branch, Electric Staff Division

FILING INSTRUCTIONS: This bulletin replaces REA Bulletin 62-1, "Design Manual for High Voltage Transmission Lines," issued August 1980 and reprinted in December 1981.

PURPOSE: This guide publication is an excellent reference of fundamental engineering guidelines and basic recommendations. The subject area includes structural and electrical aspects of standard REA wood pole line design as well as explanations and illustrations. Numerous cross-references and examples, along with the latest in design philosophy, should be of great benefit to engineers performing design work for REA borrower transmission lines. It should be particularly helpful to relatively inexperienced engineers beginning careers in transmission line design.

George E Pratt
For Administrator

9/3/92
Date

REA BULLETIN 1724E-200

DESIGN MANUAL FOR HIGH VOLTAGE TRANSMISSION LINES

ELECTRIC STAFF DIVISION

RURAL ELECTRIFICATION ADMINISTRATION

U.S. DEPARTMENT OF AGRICULTURE

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ABBREVIATIONS

(See Appendix K For Engineering Symbols And Abbreviations)

AAAC	All Aluminum Alloy Conductor
AACSR	Aluminum Alloy Conductor Steel Reinforced
ACAR	Aluminum Conductor Alloy Reinforced
ACSR	Aluminum Conductor Steel Reinforced
ACSR/AW	Aluminum Conductor Steel Reinforced/Aluminum Clad Steel Reinforced
ACSR/SD	Aluminum Conductor Steel Reinforced/Self Damping
ACSR/TW	Aluminum Conductor Steel Reinforced/Trapezoidal Wire
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWAC	Aluminum Clad Steel, Aluminum Conductor
CFR	Code of Federal Regulations
DOE	Department of Energy
IEEE	Institute of Electrical and Electronic Engineers, Inc.
M&E	Mechanical and Electrical
NESC	National Electrical Safety Code
OHGW	Overhead Ground Wire
RI	Radio Interference
ROW	Right-of-Way
SSAC	Steel Supported Aluminum Conductor
TVI	Television Interference
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
USGS	U.S. Geological Society

LIST OF TABLES

1. GENERAL PROVISIONS

1.1 Purpose: The primary purpose of this bulletin is to furnish engineering information for use in designing wood pole-type transmission lines. Good line design should result in high continuity of service, long life of physical equipment, low maintenance costs, safe operation and acceptability from an environmental standpoint.

1.2 Scope: The engineering information in this bulletin is for use in design of wood tranmission lines for voltages 230 kV and below. It is assumed that standard REA structures will be used in conjunction with data in this bulletin. Where nonstandard construction is used, factors not covered herein may have to be considered and modification in the design criteria given in this bulletin may be appropriate.

Since the REA program is national in scope, it is necessary that designs be adaptable to various conditions and local requirements. The engineer should investigate local weather information, soil conditions, operation of existing lines, local regulations, environmental requirements and evaluate known pertinent factors in arriving at design recommendations.

1.2 National Electrical Safety Code (NESC): Much of the material in this bulletin is based on the requirements of the 1990 edition of the National Electrical Safety Code, ANSI C2. In accordance with 7 CFR Part 1724, REA transmission lines are to be a minimum of Grade B construction as defined in the NESC. Since, however, the NESC is a safety code and not a design guide, additional information and design criteria are given in this bulletin as guidance to the engineer.

1.3 Responsibility: The responsibility of the borrower is to provide or obtain all engineering services necessary for sound and economical design. Due concern for the environment in all phases of construction and cleanup should be exercised.

1.4 Environmental Criteria: REA's environmental criteria are printed in 7 CFR Part 1794, "Environmental Policies and Procedures". This rule references additional laws, regulations and Executive Orders relative to the protection of the environment.

2. TRANSMISSION LINE DOCUMENTATION

2.1 Purpose: The purpose of this chapter is to provide information regarding design documentation for REA-financed transmission lines.

2.2 General: Policy and procedures pertaining to REA electric borrowers constructing transmission lines are outlined in 7 CFR 1726, "Electric System Construction and Material Purchases Policies and Procedures." Engineering design information includes design data, sample calculations, and plan-profile drawings.

2.3 Design Data Summary: A Transmission Line Design Data Summary Form, which is included in Appendix A, has been prepared to aid in the presentation of the design data summary. Where design data is required, the design data summary, or equivalent, should be submitted. A suggested outline of information to be included in a design data book necessary to support the design data summary, is also given in Appendix A. Generally, all the information indicated should be provided; however, some judgment should be used in including more or less information as appropriate.

3. TRANSMISSION LINE LOCATION AND ENGINEERING SURVEY AND RIGHT-OF-WAY ACTIVITIES

3.1 Route Selection: Transmission line routing requires thorough investigation and study of several different routings to assure that the most practical route is selected, taking into consideration both the environmental criteria and cost of construction.

In order to select and identify environmentally acceptable transmission line routes, it is necessary to identify all requirements imposed by State and Federal legislation. Environmental considerations are generally outlined in REA's Environmental Policy and Procedures, 7 CFR Part 1794, and the joint USDA-USDI publication "Environmental Criteria for Electric Transmission Systems." State public utility commissions and departments of natural resources may also designate avoidance and exclusion areas which must be considered in the routing process.

Maps are developed in order to identify the avoidance and exclusion areas and other requirements which might impinge on the line route. Ideally, all physical and environmental considerations should be plotted on one map so that the engineer can easily use this information for route evaluation. However, when there is a large number of areas to be identified or many relevant environmental concerns, more than one map may have to be prepared for clarity. The number of constraint maps which the engineer must refer to in order to analyze routing alternatives should be kept to a minimum.

Typical physical, biological and human environmental considerations are listed in Table 3-1. Suggested sources for such information are also included in the table. The order in which the considerations appear is not intended to imply any priority. Moreover, other environmental concerns may be relevant in specific situations.

For large projects, photogrammetry is contributing substantially to route selection and the designing of lines. The locating of preliminary corridors is improved when high altitude aerial photographs or satellite imagery are used to rapidly and accurately inventory existing land use. Once the preferred and alternate corridors have been selected, the engineer should consult geological survey maps, county soil, plat and road maps in order to produce small scale maps which will be used to identify additional obstructions and considerations for the preferred transmission line.

On most projects, the line lengths are short and benefits of high altitude photograph and satellite imagery quickly diminish. The engineer should consult other entities which may have previously used aerial photographs. Such entities include county planning agencies, pipeline companies, county highway departments, and land development corporations. A preliminary field survey should also be made to locate possible new features which do not appear on USGS maps of aerial photographs.

Final route selection, whether it be a large or small project, is a matter of judgment and requires sound evaluation of divergent requirements, including costs of easements, cost of clearing, ease of maintenance as well as what

TABLE 3-1
LINE ROUTING CONSIDERATIONS

Physical	Sources
• Highway	USGS, State & County Highway Department Maps
• Streams, Rivers Lakes	USGS, Army Corps of Engineers, Flood Insurance Maps
• Railroads	USGS, Railroad
• Airstrips	USGS, Federal Aviation Administration
• Topography (Major Ridge Lines, Floodplains, etc.)	USGS, Flood Insurance Maps Army Corps of Engineers
• Transmission Lines	USGS, Local Utility System Maps
Biological	
• Woodlands	USGS, USDA - Forest Service
• Wetlands	USGS, Army Corps of Engineers, U.S. Fish and Wildlife Service
• Waterfowl, Wildlife Refuge Areas, Endangered Species & Critical Habitat Areas	USDI - U.S. Fish & Wildlife Service, State Fish and Game Office
Human Environmental	
• Rangeland • Cropland • Urban Development • Industrial Development • Mining Areas • Recreation or Aesthetic Areas	USGS Aerial Survey, Satellite Mapping, County Planning Agencies, State Planning Agencies, State Soil Conservation Service,Mining Bureau, U.S. Bureau of Land Mangement
• Prime or Unique Farmland	USGS Soil Surveys, USDA- Soil Conservation Service, State Department of Agriculture, County Extension Agent
• Irrigation (Existing & Potential)	Irrigation district maps, applications for electrical service, aerial survey, State Departments of Agriculture and Natural Resources, water management districts
• Historic and Archeological Sites	National Register of Historic Sites (existing), State Historic Preservation Officer (proposed), State Historic and Archeological Societies
Other	
• Federal, State and County Controlled Lands	USGS, State Maps, U.S. Park Service, Bureau of Land Management, State Department of Natural Resources, County Maps, etc.

effect the line may have on the environment. Public relations and public input are necessary in the corridor selection and preliminary survey stages.

3.2 Reconnaissance and Preliminary Survey: Once the best route has been selected and a field examination made, aerial photos of the corridor should be reexamined to determine what corrections will be necessary for practical line location. Certain carefully located control points should then be established from an aerial reconnaissance.

Once these control points have been made, a transit line using stakes with tack points should be laid in order to fix the alignment of the line. A considerable portion of this preliminary survey usually turns out to be the final location of the line.

3.3 Right-of-Way: A right-of-way agent (or Borrower's representative) should accompany or precede the preliminary survey party in order to acquaint the property owners with the purpose of the project, the survey, and to secure permission to run the survey line. He should also be responsible for determining property boundaries crossed and maintaining good public relations. He should avoid making any commitments for individual pole locations before structures are spotted on the plan and profile sheets. However, if the landowner feels particularly sensitive about placing a pole in a particular location along the alignment, then the agent should deliver that information to the engineer, and every reasonable effort should be made by the engineer to accommodate the landowner.

As the survey proceeds, a right-of-way agent should begin a check of the records for faulty titles, transfers, joint owners, foreclosed mortgages, etc., against the ownership information ascertained from the landowners. This phase of the work requires close coordination between the engineer and the right-of-way agent. The right-of-way agent at this time must also be thinking of any access easements necessary to construct the line.

Permission may also have to be obtained to cut danger trees located outside, or for that matter, inside the right-of-way. Costly details, extravagant misuse of survey time and effort, and misunderstanding on the part of the landowners are to be avoided.

3.4 Line Survey: Immediately after the alignment of a line has been finalized to the satisfaction of both the engineer and the borrower, a survey should be made to map the route of the line. The results of the survey will be plan-profile drawings which will be used to spot structures. The accuracy of the survey should be to third order.

Long corridors can usually be mapped by photogrammetry at less cost than equivalent ground surveys. The photographs will also contain information and details which could not otherwise be discovered or recorded. Aerial survey of the corridor can be done rapidly, but the proper conditions for photography occur only on a comparatively few days during the year. In certain areas, photogrammetry is impossible. It cannot be used where high conifers conceal the ground or in areas such as grass-covered plains that contain no discernible objects. The necessary delays and overhead costs inherent in air mapping usually prevent their use for short lines.

When using aerial photogrammetry to develop plan-profile drawings, proper horizontal and vertical control should first be established in accordance with accepted methods. From a series of overlapping aerial photographs, a plan of the transmission line route can be made. The plan may be in the form of an orthophoto or it may be a planimetric map (see Chapter 10). The overlapping photos also enable the development of profile drawings. The tolerance of plotted ground elevations to the actual ground profile will depend on photogrammetric equipment, flying height, and accuracy of control points.

If the use of photogrammetry for topographic mapping is not applicable for a particular line, then transit and tape or various electronic instruments for measuring distance should be used to make the route survey. This survey will generally consist of placing stakes at 30.5 meter (100 foot) intervals with the station measurement suitably marked on the stakes. It will also include the placement of intermediate stakes to note the station at property lines and reference points as required. These stakes should be aligned by transit between the hub stakes set on the preliminary survey. The survey party shall keep notes showing property lines and topographic features of obstructions that would influence structure spotting. Colored ribbon or strips of cloth should be attached at all fence crossings and to trees at regular intervals along the route wherever possible, so as to facilitate the location of the route by others.

As soon as the horizontal control survey is sufficiently advanced, a level party should start taking ground elevations along the center line of the survey. Levels should be taken at every 30.5 meter (100 foot) stations and at all intermediate points where breaks in the ground contour appear. Wherever the ground slopes more than 10 percent across the line of survey, side shots should be taken for a distance of at least 3 meters (10 feet) beyond the outside conductor's normal position. These elevations to the right and left of the center line should be plotted as broken lines. These broken lines represent sidehill profiles and are necessary in spotting structures to assure proper ground clearance under all conductors, and proper pole lengths and setting depths for multiple-pole structures.

3.5 <u>Drawings</u>: As soon as the route survey has been obtained, the plan and profile should be prepared. The information on the plan and profile should include the alignment, stationing, calculated courses, fences, trees, roads, ditches, streams, and swamps. The vertical and plan location of telecommunications, transmission and other electric lines should be included since they effect the proposed line. Also, to be shown are railroads and river crossings, property lines, with the names of the property owners, along with any other features which may be of value in the right-of-way acquisition, design, construction, and operation of the line. Chapter 10 discusses structure spotting on the plan-profile.

Structure spotting should begin after all of the topographic and level notes are plotted on the plan and profile sheets. Prints of the drawings should be furnished to the right-of-way agent for checking property lines and for recording easements. One set of prints certified as to the extent of permits, easements, etc., that have been secured by the borrower should be returned to the engineer.

3.6 <u>Rerouting</u>: During the final survey, occasions may arise where considerations should be given to rerouting small segments of the line due to the inability of the right-of-way agent to satisfy the demands of a property owner. In such instances, the engineer should ascertain the costs and public attitudes towards all reasonable alternatives. The engineer should then decide to either satisfy the property owner's demands, relocate the line, initiate condemnation proceedings, or take other action as appropriate.

3.7 <u>Clearing Right-of-Way</u>: The first actual work to be done on a transmission line is usually clearing the right-of-way. When clearing, it is important that the environment be considered. It is also important that the clearing be done in such a manner that will not interfere with the construction, operation or maintenance of the line. In terrain having heavy timber, prior partial clearing may be desirable to facilitate surveying. Preferably, all right-of-way for a given line should be secured before starting construction. See Chapter 5 for a discussion of right-of-way width.

3.8 <u>Responsibility</u>: The engineer is responsible for coordinating right-of-way clearing, structure staking and construction of the project in such a manner that no unnecessary delays will result.

3.9 <u>Permits, Easements, Licenses, Franchises, and Authorizations</u>: The following is a list of permits, easements, licenses, franchises, and authorizations that commonly need to be obtained. This list is not meant to be exhaustive.

a. Private property: Easement from owner and permission to cut danger trees.
b. Railroad: Permit or agreement.
c. Highway: Permit from state.
d. Other public bodies: Authorization.
e. City, County or State: Permit.
f. Joint and common use pole: Permit or agreement.
g. Wire crossing: Permission of utility.
h. Navigable stream: Permit from U.S. Army Corps of Engineers.
i. U.S. Government property: Permit.
j. Airport and airways: Coordinate with Federal Aviation Agency.
k. Federal Energy Regulatory Commission, DOE: License
l. U.S. Forest Service: Permit.
m. National Park Service: Permit.
n. Indian Tribal Reservation: Easement.
o. Bureau of Land Management: Permit.

4. CLEARANCES TO GROUND, TO OBJECTS UNDER THE LINE, AND AT CROSSINGS

4.1 General: The recommended minimum vertical clearances for REA-financed AC transmission line designs of 230 kV and below are listed in the tables below. These clearances exceed the minimum clearances calculated in accordance with the 1990 edition of the NESC. If the 1990 edition has not been adopted in a particular locale, the clearances and the conditions found in this chapter should be reviewed to insure that they meet the more stringent of the applicable requirements.

It is recommended that clearances less than those specified in the tables should not be used.

4.2 Assumptions

4.2.1 Fault Clearing: The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

4.2.2 Voltage: Listed below are nominal transmission line voltages and the assumed maximum allowable operating voltage for each level. If the expected operating voltage is greater than the value given below, the clearances in this bulletin may be inadequate. Refer to the 1990 edition of the NESC for guidance.

Nominal Line-to-Line Voltage (kV)	Maximum Line-to Line Voltage (kV)
34.5	*
46	*
69	72.5
115	121
138	145
161	169
230	242

*Maximum operating voltage has no effect on clearance requirements for these nominal voltages.

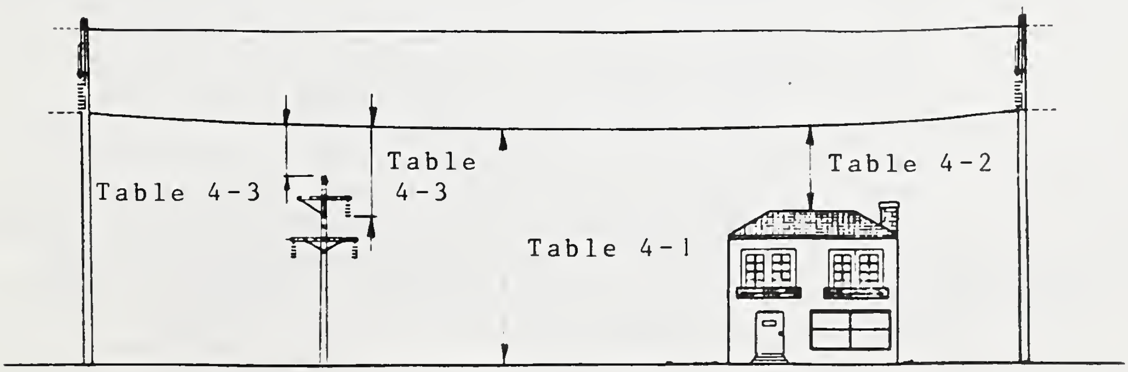


FIGURE 4-1: CLEARANCE SITUATIONS COVERED IN THIS CHAPTER

4.3 Minimum Vertical Clearance of Conductors: The recommended minimum vertical clearances under various conditions are given in Table 4-1.

4.3.1 Conditions Under Which Clearances Apply: The clearances apply to a conductor at final sag for the condition below yielding the greatest sag for the line.

a. A conductor temperature of 0°C (32°F), no wind, with the radial thickness of ice for the applicable loading district.

b. A conductor temperature of 75°C (167°F). A lower temperature may be considered where justified by a qualified engineering study. Under no circumstances should a design temperature be less than 49°C (120°F).

c. Maximum design conductor temperature, no wind, under emergency loading conditions. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 100°C (212°F) as the maximum design conductor temperature.

According to the National Electric Reliability Council Criteria, emergency loading for the lines of a system would be those line loads that would be sustained when the worst combination of one line and one generator outage occurs. The loads used for case "c" should be based on long range load forecasts.

4.3.2 Altitude Greater than 1000 Meters (3300 Feet): If the altitude of a transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated in Table 4-1 must be added to the base clearances given.

4.3.3 Spaces and Ways Accessible to Pedestrians Only: These clearances should be applied carefully. If it is possible for anything other than a person on foot to get under the line, such as a person riding a horse, the line should not be considered to be accessible to pedestrians only and another clearance category should be used. It is expected that this type of clearance will be used rarely and only in the most unusual circumstances.

4.3.4 Clearance for Lines Along Roads in Rural Districts: If a line along a road in a rural district is adjacent to a cultivated field or other land falling into Category 3 of Table 4-1, the clearance-to-ground should be based on the clearance requirements of Category 3 unless the line is located entirely within the road right-of-way and is inaccessible to vehicular traffic, including highway right-of-way maintenance equipment. If a line meets these two requirements, its clearance may be based on the "along road in rural district" requirement. In order to avoid the need for future line changes, it is strongly recommended that if it is considered likely a driveway will be built somewhere under the line, the ground clearance for the line should be based on clearance over driveways. Heavily traveled rural roads should be considered as being in urban areas.

4.3.5 <u>Tall Vehicles</u>: In those areas where it can be normally expected that vehicles with an overall operating height greater than 4.3 meters (14 feet) will pass under the line, it is recommended that consideration be given to increasing the clearances given in Table 4-1 by the amount by which the vehicle's operating height exceeds 4.3 meters (14 feet).

4.3.6 <u>Clearances Over Water</u>: Clearances over navigable waterways are governed by the U. S. Army Corps of Engineers and therefore the clearances over water given in Table 4-1 apply only where the Corps does not have jurisdiction.

4.3.7 <u>Clearances for Sag Templates</u>: Sag templates used for spotting structures on a plan and profile sheet should be cut to allow at least .3 meters (1 foot) extra clearance than given in Table 4-1, in order to compensate for minor errors and to provide flexibility for minor shifts in structure location.

Where the terrain or survey method used in obtaining the ground profile for the plan and profile sheets is subject to greater unknowns or tolerances than the 0.3 meters (1 foot) allowed, appropriate additional clearance should be provided.

4.4 <u>Minimum Vertical Clearance of Conductors to Objects Under the Line (not including conductors of other lines)</u>: The recommended minimum vertical clearances to various objects under a transmission line are given in Table 4-2.

4.4.1 <u>Conditions Under Which Clearances Apply</u>: The clearances in the table are to be met if the horizontal clearance requirements to the same objects are not met (see Chapter 5). The clearances in the table apply under the same loading and temperature conditions as outlined in section 4.3.1 above.

4.4.2 <u>Lines Over Buildings</u>: Although clearances for lines passing over buildings are given, it is recommended that lines not pass directly over a building if it can be at all avoided.

4.4.3 <u>Lines Over Swimming Pools</u>: Clearances over swimming pools are given for reference purposes only. Lines should not pass over or within 7.6 meters (25 feet) of the edge of a swimming pool if at all possible.

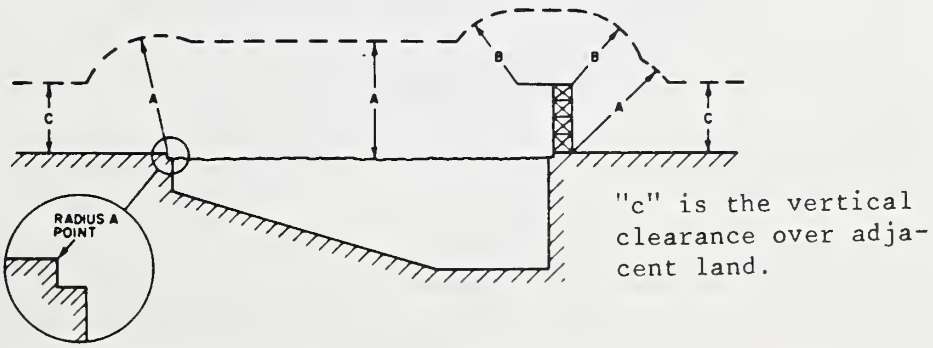


FIGURE 4-2: SWIMMING POOL CLEARANCES

TABLE 4-1

RECOMMENDED MINIMUM VERTICAL CLEARANCE OF
CONDUCTORS-TO-GROUND IN METERS (FEET)

CLEARANCE REQUIRED WHEN CONDUCTORS CROSS OVER:	Nominal Line-to-Line Voltage in kV: 34.5-69	115	138	161	230
1. Railroad tracks	9.0 (29.6)	9.3 (30.6)	9.5 (31.1)	9.6 (31.5)	10.1 (33.0)
2. Roads, streets, alleys, parking lots or driveways	6.6 (21.6)	6.9 (22.6)	7.0 (23.1)	7.2 (23.5)	7.6 (25.0)
3. Land that may be traversed by vehicles such as cultivated, grazing, forest, orchards, etc. (B)	6.6 (21.6)	6.9 (22.6)	7.0 (23.1)	7.2 (23.5)	7.6 (25.0)
4. Spaces and ways accessible to pedestrians only (C)	5.1 (16.6)	5.4 (17.6)	5.5 (18.1)	5.7 (18.5)	6.1 (20.0)
5. Water areas not suitable for sailboating or where sailboating is not permitted (E)	5.4 (17.6)	5.7 (18.6)	5.8 (19.1)	5.9 (19.5)	6.4 (21.0)
6. Water areas suitable for sailboating including lakes, ponds, reservoirs, rivers, streams, and canals with unobstructed surface area of (D) (E)					
a. Less than 8 ha (A) (20 acres)	6.6 (21.6)	6.9 (22.6)	7.0 (23.1)	7.2 (23.5)	7.6 (25.0)
b. Over 8 to 80 ha (over 20 to 200 acres)	9.0 (29.6)	9.3 (30.6)	9.5 (31.1)	9.6 (31.5)	10.1 (33.0)
c. Over 80 to 800 ha (over 200 to 2000 acres)	10.9 (35.6)	11.2 (36.6)	11.3 (37.1)	11.5 (37.5)	11.9 (39.0)
d. Over 800 ha (over 2000 acres)	12.7 (41.6)	13.0 (42.6)	13.1 (43.1)	13.3 (43.5)	13.7 (45.0)
7. Land and water areas for rigging and launching sailboats (E)	Clearance above ground shall be 1.5 meters (5 feet) greater than in No. 6 above for the water area served by the launching site.				

TABLE 4-1 (CONT.)

RECOMMENDED MINIMUM VERTICAL CLEARANCE
OF CONDUCTORS-TO-GROUND IN METERS (FEET)

CLEARANCE REQUIRED WHEN CONDUCTORS RUN ALONG THE TRAVELED WAY OR ADJACENT LAND AND WITHIN THE LIMITS OF THE RIGHT-OF-WAY BUT DO NOT OVERHANG:	Nominal Line-to-Line Voltage in kV 34.5-69	115	138	161	230
8. Roads in rural districts (F)	6.0 (19.6)	6.3 (20.6)	6.4 (21.1)	6.6 (21.5)	7.0 (23.0)
9. Streets or alleys in urban districts	6.6 (21.6)	6.9 (22.6)	7.0 (23.1)	7.2 (23.5)	7.6 (25.0)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 300 meters of altitude above 1000 meters (additional feet of clearance per 1000 feet of altitude above 3300 feet)	.01 (.02)	.016 (.05)	.02 (.07)	.025 (.08)	.04 (.12)

NOTES:

(A) 1 hectare = 2.47 acres.
(B) These clearances are for land traversed by vehicles and equipment whose overall operating height is less than 4.3 meters (14 feet).
(C) Areas accessible to pedestrians only are areas where equestrians, vehicles or other mobile units, exceeding 8 feet in height are prohibited by regulation or permanent terrain configurations or are not encountered or reasonably anticipated. Land subject to highway right-of-way maintenance equipment shall not be considered as being accessible to pedestrians only.
(D) The surface area and corresponding clearance shall be based upon the uncontrolled 10 year flood level, or for controlled impoundments, upon the design high water level. The clearance over rivers, streams, and canals shall be based upon the surface area of the largest 1.6 kilometer (1 mile) long segment which includes the crossing and which has the greatest surface area. The clearance over a canal or similar waterway providing access for sailboats to a larger body of water shall be the same as that required for the larger body of water.
(E) Where the U.S. Army Corps of Engineers has issued a crossing permit, the clearances of that permit shall govern.
(F) Heavily traveled roads, even if they are located in rural areas, should be considered as being in urban areas.

TABLE 4-2

RECOMMENDED MINIMUM CONDUCTOR CLEARANCES
TO OBJECTS UNDER LINES, METERS (FEET)
(Applies only to lines with
automatic ground fault relaying)

CLEARANCES WHEN CONDUCTORS CROSS OVER:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
1. Building roofs or projections not accessible to pedestrians	4.5 (14.6)	4.8 (15.6)	4.9 (16.1)	5.0 (16.5)	5.5 (18.0)
2. Building roofs, balconies or projections accessible to pedestrians	5.1 (16.6)	5.4 (17.6)	5.5 (18.1)	5.6 (18.5)	6.1 (20.0)
3. Signs, chimneys, radio & television antennas, tanks, and other installations not classified as buildings or bridges	3.1 (10.1)	3.4 (11.1)	3.5 (11.6)	3.7 (12.0)	4.1 (13.5)
4. Lighting supports, traffic signals, or a supporting structure of another line	2.1 (7.0)	2.7 (8.6)	2.8 (9.1)	2.9 (9.5)	3.4 (11.0)
5. Swimming pools Clearance A*	8.3 (27.1)	8.6 (28.1)	8.7 (28.6)	8.8 (29.0)	9.3 (30.5)
Clearance B*	5.5 (18.1)	5.8 (19.1)	6.0 (19.6)	6.1 (20.0)	6.5 (21.5)
6. Grain bins loaded by portable augers, conveyors or elevators	6.1 (20.1)	6.4 (21.1)	6.6 (21.6)	6.7 (22.0)	7.2 (23.5)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 300 meters of altitude above 1000 meters (additional feet of clearance per 1000 feet of altitude above 3300 feet.)	.01 (.02)	.016 (.05)	.02 (.07)	.025 (.08)	.04 (.12)

*See Figure 4-2.

4.5 Minimum Vertical Clearance Between Conductors Where One Line Crosses Over or Under Another: The recommended minimum vertical clearances between conductors when one line crosses another are given in Table 4-3. When a transmission line crosses another and both conductors are knownn to have ground fault relaying, the values from section 4 of the table should be used. If it is not known whether the transmission line crossed has ground fault relaying, the values from section 5 of the table should be used. The clearances given should be maintained at the point where the conductors cross, regardless of where on the span the point of crossing is.

4.5.1 Conditions Under Which Clearances Apply: The clearances apply for an upper conductor at final sag for that condition below that yields the greatest sag for the line in question.

a. A conductor temperature of 0°C (32°F), no wind, with a radial thickness of ice for the loading district concerned.

b. A conductor temperature of 75°C (167°F). See section 4.3.1.b.

c. Maximum conductor temperature, no wind, under emergency loading conditions. See section 4.3.1. The same maximum temperature used for vertical clearance to ground should be used.

The lower conductor sag to be used in conjunction with Table 4-3 is the initial sag at 16°C (60°F), no wind. If such a sag value is not available, the best available estimates of such sags should be used.

4.5.2 Altitude Greater than 1000 Meters (3300 Feet): If the altitude of the crossing point of the two lines is greater than 1000 meters (3300 feet), additional clearance as indicated in Table 4-3 must be added to the base clearance given.

4.5.3 Differences in Sag Conditions Between Lower and Upper Conductors: The reason for the difference in sag conditions between the upper and lower conductor at which the clearances apply is to cover situations where the lower conductor has lost its ice while the upper conductor has not, or where the upper conductor is loaded to its thermal limit while the lower conductor is only lightly loaded.

4.6 Minimum Vertical Clearance Between Conductors of Different Lines at Noncrossing Situations: If the horizontal separation between conductors as set forth in Chapter 5 is not met, then the clearance requirements in Section 4.5 above should be met.

4.7 Example of Minimum Line-to-Ground Clearance: A portion of a 161 kV line is to be built over a field of oats that is at an elevation of 2200 meters (7200 feet). Determine the minimum line-to-ground clearance.

TABLE 4-3

RECOMMENDED MINIMUM VERTICAL CLEARANCE IN METERS (FEET) BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF ONE LINE CROSS OVER THE CONDUCTORS OF ANOTHER WHERE UPPER CONDUCTOR HAS GROUND FAULT RELAYING

CLEARANCE REQUIRED BETWEEN UPPER AND LOWER LEVEL CONDUCTORS	UPPER LEVEL CONDUCTOR (A) Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
Lower Level Conductor					
1. Communication lines	2.0 (6.5)	2.4 (7.7)	2.5 (8.2)	2.6 (8.6)	3.1 (10.0)
2. Overhead ground wire (B)	1.5 (4.7)	1.8 (5.7)	1.9 (6.2)	2.0 (6.6)	2.5 (8.0)
3. Distribution conductors	1.4 (4.6)	1.7 (5.6)	1.9 (6.1)	2.0 (6.5)	2.5 (8.0)
4. Transmission conductors of lines that have ground fault relaying. Nominal line-to-line voltage in kV.					
a. 69 and below	1.5 (4.7)	1.8 (5.7)	1.9 (6.2)	2.0 (6.6)	2.5 (8.0)
b. 115		1.9 (6.3)	2.1 (6.8)	2.2 (7.3)	2.7 (8.7)
c. 138			2.2 (7.3)	2.4 (7.7)	2.8 (9.1)
d. 161				2.5 (8.2)	2.9 (9.6)
e. 230					3.4 (11.0)

5. Transmission conductors of lines that do not have ground fault relaying. Nominal voltage in kV.	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
a. 46 and below	1.5 (4.7)	1.5 (4.7)	1.8 (5.7)	1.9 (6.2)	2.0 (6.6)	2.5 (8.0)
b. 69		1.5 (4.7)	2.0 (6.4)	2.1 (6.9)	2.3 (7.4)	2.7 (8.8)
c. 115			2.5 (8.0)	2.6 (8.5)	2.8 (9.0)	3.2 (10.4)
d. 138				2.9 (9.3)	3.0 (9.8)	3.4 (11.2)
e. 161					3.2 (10.6)	3.7 (12.0)
f. 230						4.4 (14.4)

TABLE 4-3 (CONT.)

RECOMMENDED MINIMUM VERTICAL CLEARANCE IN METERS (FEET)
BETWEEN CONDUCTORS WHERE THE CONDUCTORS OF ONE LINE
CROSS OVER THE CONDUCTORS OF ANOTHER WHERE UPPER
CONDUCTOR HAS GROUND FAULT RELAYING

ALTITUDE CORRECTION TO
BE ADDED TO VALUES ABOVE:

Total altitude correction factor = Correction for upper conductors + Correction for lower conductors

For upper conductors use correction factor from Table 4-1.

For lower conductors:

Categories 1, 2 and 3 above use no correction factors.

Category 4 uses correction factors from Table 4-1.

Category 5 uses the following:

Additional meters of clearance per 300 meters above 1000 meters (additional feet of clearance per 1000 feet of altitude above 3300 feet.)	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
	0 (0)	.01 (.02)	.016 (.05)	.02 (.07)	.025 (.08)	.04 (.12)

NOTES:

(A) The higher voltage line should cross over the lower voltage line.
(B) If the line on the lower level has overhead ground wire(s), this clearance will usually be the limiting factor at crossings.

4.7.1 Determination of the Additional Clearance for Altitude: Because the altitude is greater than 1000 meters (3300 feet), the basic clearance must be increased by the amount indicated in Table 4-1, which is .08 meters per 1000 meters above 1000 meters, or .025 feet per 1000 feet above 3300 feet.

$$\frac{(2200 - 1000)(.025)}{300} = .10 \text{ meters}$$

$$\frac{(7200 - 3300)(.08)}{1000} = .312 \text{ feet (round to .32 feet)}$$

4.7.2 Total clearance: Assuming the line meets the assumptions given in 4.2 of this chapter, from Table 4-1 the required minimum clearance over cultivated field for a 161 kV line is 7.3 meters (23.8 feet).

$$.01\text{m} + 7.2\text{m} = 7.3\text{m}$$

$$.32 \text{ ft.} + 23.5 \text{ ft.} = 23.8 \text{ ft.}$$

(The sag template should be drawn for at least .3m (1 ft.) additional).

4.8 Example of Conductor Crossing Clearances: A 230 kV line crosses over a 115 kV line in two locations. At one location the 115 kV line has an overhead ground wire which at the point of crossing is 3.05 meters (10 feet) above its phase conductors. At the other location the lower voltage line does not have overhead ground wires. Determine the required clearance between the 230 kV conductors and the 115 kV conductors at both crossing locations. Assume that the altitude of the line is below 1000 meters (3300 feet). Also assume that the sag of the overhead ground wire is the same as or less than the sag of the 115 kV phase conductors.

4.8.1 Solution: The first step in the solution is to determine if the line that is crossed over has automatic ground fault relaying. Let us assume that we are unable to make such a determination and therefore to be safe, we must assume that the line does not have such relaying.

From Table 4-3, section 5, the required clearance from the 230 kV conductor to the 115 kV conductor is 3.2 meters (10.4 feet). From Table 4-3, section 2, the required clearance from the 230 kV conductor to the overhead ground wire is 2.5 meters (8.0 feet); adding 3.05 meters (10 feet) for the distance between the OHGW and the 115 kV phase conductors, we get a total required clearance of 5.55 meters (18 feet).

When the lower circuit has an overhead ground wire, the clearance requirements to the overhead ground wire govern and the required clearance between the upper and lower phase conductor is 5.5 meters (18 feet).

Where there is no overhead ground wire for the 115 kV circuit, the required clearance between the phase conductors is 3.2 meters (10.4 feet).

It should be stressed that the above clearance values must be maintained where the upper conductor is at its maximum sag condition as defined in section 4.4.1.a above, and the lower conductor is at 16°C (60°F) initial sag.

5. HORIZONTAL CLEARANCE FROM LINE CONDUCTORS TO OBJECTS AND RIGHT-OF-WAY WIDTH

5.1 General: The preliminary comments and assumptions of Chapter 4 also apply to this chapter.

5.2 Minimum Horizontal Clearance of Conductor to Objects: The recommended minimum horizontal clearance of conductors to various objects are given in Table 5-1. The clearances apply only for lines that are capable of automatically clearing line-to-ground faults.

5.2.1 Conditions Under Which Clearances Apply: The clearances apply when the conductor is displaced by a .29 kilopascals (6 pounds per square foot) wind, at 16°C (60°F). The sag value to be used is the final sag at 16°C (60°F) with .29 kilopascals (6 pounds per square foot) of wind. See Figure 5-1.

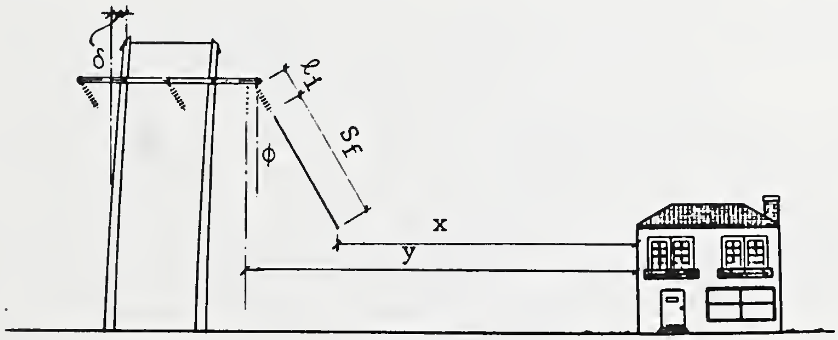


FIGURE 5-1: HORIZONTAL CLEARANCE REQUIREMENT

ϕ = conductor swing out angle in degrees under .29 kilopascals (6 lbs/sq. ft.) of wind.
S_f = conductor final sag at 16°C (60°F) with .29 kilopascals (6 lbs/sq. ft.) of wind.
x = clearance required per Table 5-1 (include altitude correction if necessary).
ℓ_i = insulator string length (ℓ = 0 for post insulators or restrained suspension insulators).
y = total horizontal distance from insulator suspension point (conductor attachment point for post insulators) to structure.
δ = structure deflection with a .29 kilopascals (6 lbs/sq. ft.) wind.

TABLE 5-1

RECOMMENDED MINIMUM HORIZONTAL CLEARANCE
FROM CONDUCTORS TO OBJECTS NEAR THE
LINE IN METERS (FEET)

CLEARANCE TO:	Nominal Line-to-Line Voltage in kV				
	34.5-69	115	138	161	230
1. Buildings, signs, chimneys, and television antennas, tanks containing nonflammables, and other installations not classified as buildings or bridges.	3.0 (9.6)	3.3 (10.6)	3.4 (11.1)	3.5 (11.5)	4.0 (13.0)
2. Lighting supports, traffic signals, or supporting structures of another line.	2.0 (6.5)	2.5 (8.1)	2.6 (8.6)	2.7 (9.0)	3.2 (10.5)
3. Rail of railroad tracks.	4.5 (14.6)	4.7 (15.6)	5.0 (16.1)	5.1 (16.5)	5.5 (18.0)
4. Grain bins loaded by portable augers, conveyor or elevators.	6.2 (20.1)	6.5 (21.1)	6.6 (21.6)	6.7 (22.0)	7.2 (23.5)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:					
Additional meters of clearance per 300 meters of altitude above 1000 meters (additional feet of clearance per 1000 feet of altitude above 3300 feet).	.01 (.02)	.016 (.05)	.04 (.07)	.025 (.08)	.04 (.12)

5.2.2 <u>Altitude Greater Than 1000 Meters (3300 Feet)</u>: If the altitude of the transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated in Table 5-1 must be added to the base clearance given.

5.2.3 <u>Total Horizontal Clearance to Point of Insulator Suspension to Object</u>: As can be seen from Figure 5-1, the total horizontal clearance value (y) is:

$$y = (\ell_i + S_f) \sin \phi + x + \delta \qquad \text{Eq. 5-1}$$

Symbols are defined in 5.2.1.

The factor "δ" indicates that structure deflection should be taken into account. Generally, for single pole wooden structures, it can be assumed that the deflection under .29 kilopascals (6 lbs/sq. ft.) of wind will not exceed 5 percent of the structure height above the groundline. For unbraced H-frame structures the same assumption can be made. For braced H-frame structures, the deflection under .29 kilopascals (6 lbs/sq. ft.) of wind will be

considerably less than that for a single pole structure, and is often assumed to be insignificant.

For the sake of simplicity in determining horizontal clearances only, the insulator string should be assumed to have the same swing angle as the conductor. This assumption should only be made in this chapter as its use in other calculations may not be appropriate.

The conductor swing angle (ϕ) under .29 kilopascals (6 lbs/sq. ft.) of wind can be determined from the formulae.

$$\phi = \tan^{-1}\left(\frac{(d_c)(F)}{1000\ w_c}\right) \qquad \text{(Metric) Eq. 5-2}$$

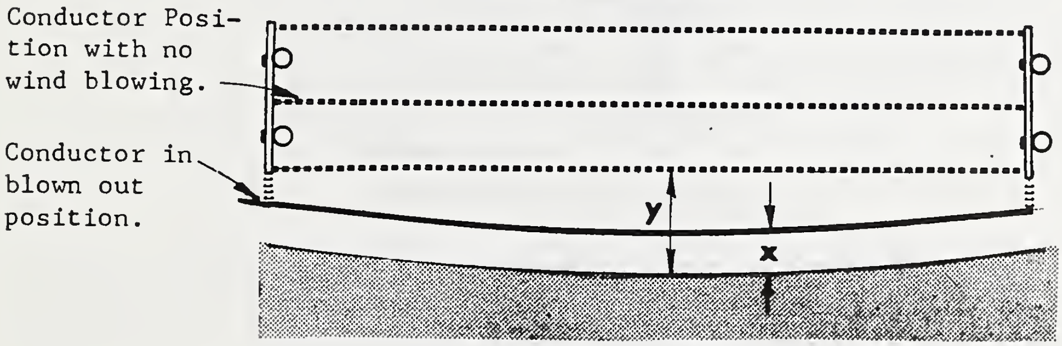
$$\phi = \tan^{-1}\left(\frac{(d_c)(F)}{12\ w_c}\right) \qquad \text{(English) Eq. 5-3}$$

Where:

d_c = conductor diameter in millimeters (inches).
w_c = weight of conductor in Newtons per meter (lbs. per foot)(for standard gravity 1kg = 9.81N).
F = wind force. Use .29 kPa (6 lbs/sq. ft.) for this case.

The total horizontal distance (y) at a particular point in the span depends upon the conductor sag at that point. The value of (y) for a structure adjacent to the maximum sag point will be greater than the value of (y) for a structure placed elsewhere along the span. See Figure 5-2.

Top View of a Line



x = clearance required per Table 5-1
y = total horizontal clearance

FIGURE 5-2: A TOP VIEW OF A LINE SHOWING TOTAL HORIZONTAL CLEARANCE REQUIREMENTS

5.3 <u>Right-of-Way (ROW) Width:</u> For transmission lines, a right-of-way is necessary so that an environment can be established and maintained that allows

the line to be operated and maintained safely and reliably. The determination of the right-of-way width is a task that requires the consideration of a variety of judgmental, technical, and economic factors.

Nominal right-of-way widths (predominantly H-frames) that have been used by REA borrowers in the past are shown below. In many cases a range of widths is given. The actual width used will depend upon the particulars of the line design. The widths have generally proven to be satisfactory and in most instances provide sufficient width so that if a line structure falls, it will remain within the right-of-way.

	Nominal Line-to-Line Voltage in kV				
	69	115	138	161	230
ROW Width in meters	22-30	30	30-45	30-45	40-60
(feet)	(75-100)	(100)	(100-150)	(100-150)	(125-200)

5.4 Calculation of Right-of-Way Width for a Single Line of Structures on a Right-of-Way: Instead of using the nominal right-of-way width given above, widths can be calculated using either of the two methods below. They yield values that are more directly related to the particular parameters of the line design.

5.4.1 First Method: This method provides sufficient width so that if a building of undetermined height is built at any place directly on the edge of the right-of-way, the clearance requirements to buildings will be met.

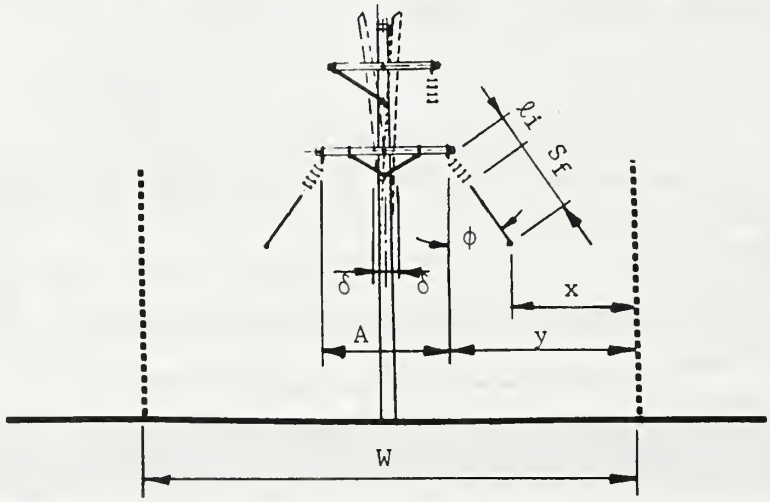


FIGURE 5-3: ROW WIDTH FOR SINGLE LINE OF STRUCTURES (FIRST METHOD)

W = total right-of-way width required.
A = separation between points of suspension of insulator strings for outer two phases.
x = clearance required per Table 5-1 (include altitude correction if necessary).

Other symbols are as previously defined.

The question arises as to what span length (and thus what sag) should the right-of-way width be based. There are two ways of approaching this question. One is to use one width for the entire line and to base that width on the maximum span length in the line. The other way is to base the width on a relatively long, but not the longest span (say the ruling span, for instance). For those spans that exceed this base span, additional width would be added as appropriate.

5.4.2 <u>Second Method</u>: If there is an extremely low probability of structures being built near the line, the right-of-way width could be based on allowing the phase conductor to blow out to the edge of the right-of-way under extreme wind conditions such as the 50 or 100-year mean wind.

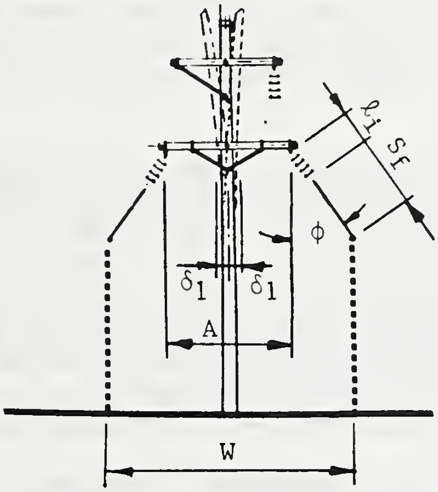


FIGURE 5-4: ROW WIDTH FOR SINGLE LINE OF STRUCTURES (SECOND METHOD)

ϕ = conductor swing out angle in degrees at extreme wind conditions.
S_f = conductor final sag at extreme wind conditions at the temperature at which the wind is expected to occur.
δ_1 = structure deflection under extreme wind conditions.

Other symbols are as previously defined.

Figure 5-4 above illustrates the right-of-way width determination for the second method. From the figure above it can be seen that the formula for the width is:

$$W = A + 2(\ell_i + S_f) \sin \phi + 2\delta_1 \qquad \text{Eq. 5-4}$$

where:

ϕ can be determined using Equations 5-2/5-3 with a wind force value F for the extreme wind condition (see Appendix E for conversion of wind velocity to wind pressure).

All symbols are as defined above.

As with the previous method, the sags in the calculations can be based on either the maximum span or the ruling span, with special consideration given to spans longer than the ruling span.

5.5 Right-of-Way Width for a Line Directly Next to a Road: The right-of-way width for a line next to a road can be calculated based on the two previous sections with one exception. No ROW is needed on the road side of the line as long as the appropriate clearances to existing or possible future structures on the road side of the line are met.

If a line is to be put next to a roadway, consideration should be given to whomever will pay for the cost of moving the line if the road is widened. Generally, if the line is on the road right-of-way, the borrower would pay to move it; and if it is on private land, the highway department would pay. The choice of putting a line on a road right-of-way would depend on local ordinances and requirements, plus an estimation of the probability of the road being widened.

5.6 Right-of-Way Width for Two or More Lines of Structures on a Single Right-of-Way: The determination of the right-of-way width where there are two parallel lines on the same right-of-way can be broken into two parts. The distance from the outside phases of the lines to the ROW edge is calculated in the same manner as given in section 5.4 above. The distance between the lines is governed by three separate sets of criteria, given below, any one of which may be governing. If one of the lines involved is an EHV line (345 kV and above), the National Electrical Safety Code should be referred to for additional applicable clearance rules not covered in this bulletin.

5.6.1 Separation Between Lines as Dictated by Minimum Clearance Between Conductors Carried on Different Supports: The horizontal clearance between a phase conductor of one line to a phase conductor of another line shall meet the largest of C_1, C_2, or C_3 below, under the following conditions: (a) both phase conductors displaced by a .29 kilopascal (6 lbs/sq. ft.) wind at 16°C (60°F), final sag; (b) if insulators are free to swing, one should be assumed to be displaced by a .29 kPa (6 lbs/sq. ft.) wind while the other should be assumed to be unaffected by the wind (see Figure 5-5). The wind direction assumed should be that which results in the greatest separation requirement. It should be noted that in the equations that follow, the $(\delta_1-\delta_2)$ term, the differential structure deflection between the two lines of structures involved, must be taken into account. See section 5.4 for further discussion on deflections.

Metric Form

$C_1 = 1.6 + (\delta_1 - \delta_2)$ Eq. 5-5

$C_2 = .610 + .0102[(kV_{LG1}+kV_{LG2}) - 8.7] + (\delta_1 - \delta_2)$ Eq. 5-6

$C_3 = .00762[(kV_{LG1}+kV_{LG2})+(kV_{LG1}+kV_{LG2}-50)] + F_c\sqrt{S_f(.3048)}$ Eq. 5-7

English Form

$C_1 = 5 + (\delta_1 - \delta_2)$ Eq. 5-8

$C_2 = 2 + \frac{.4}{12}[(kV_{LG1} + kV_{LG2}) - 8.7] + (\delta_1 - \delta_2)$ Eq. 5-9

$C_3 = .025[(kV_{LG1} + kV_{LG2}) + (kV_{LG1} + kV_{LG2} - 50)] + F_c\sqrt{S_f}$ Eq. 5-10

where:

C_1, C_2, C_3 = clearance requirements between conductors on different lines in meters (feet) (largest value governs).
kV_{LG1} = maximum line-to-ground voltage in kV of line 1.
kV_{LG2} = maximum line-to-ground voltage in kV of line 2.
S_f = the final sag of conductor in meters (feet) at 16°C (60°F).
F_c = experience factor; can be 1.4 to .67. (See Chapter 6)
δ_1 = deflection of the upwind structure in meters (feet).
δ_2 = deflection of the downwind structure in meters (feet).

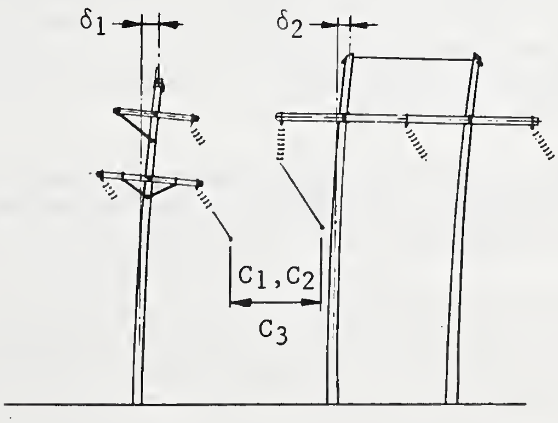


FIGURE 5-5: CLEARANCE BETWEEN CONDUCTORS OF ONE LINE TO CONDUCTOR OF ANOTHER LINE

5.6.2 <u>Separation Between Lines as Dictated by Minimum Clearance of Conductors From One Line to the Supporting Structure of Another</u>: The horizontal clearance of a phase conductor of one line to the supporting structure of another when the conductor and insulator are displaced by a .29 kPa (6 lbs/sq. ft.) wind at 16°C (60°F) final sag must meet:

$$C_4 = 1.9 + .0102(kV_{LG} - 50) + (\delta_1 - \delta_2) \quad \text{(Metric) Eq. 5-11}$$

$$C_4 = 6' + \frac{.4}{12}(kV_{LG} - 50) + (\delta_1 - \delta_2) \quad \text{(English) Eq. 5-12}$$

where:

kV_{LG} = the maximum line-to-ground voltage in kV.
C_4 = the clearance of conductors of one line to structure of another in meters (feet).
Other symbols as previously defined.

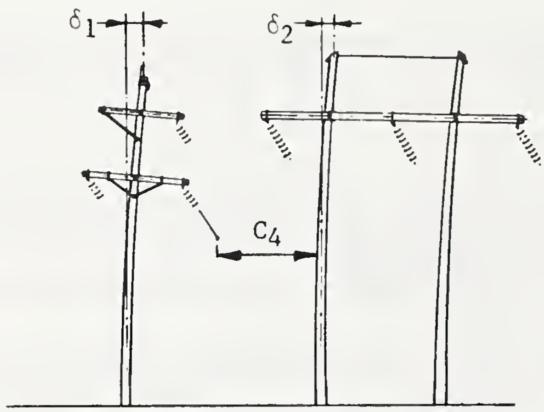


FIGURE 5-6: CLEARANCE BETWEEN CONDUCTOR OF ONE LINE AND STRUCTURE OF ANOTHER

The separation between lines will depend upon the spans and sags of the lines as well as how the structures of one line match up with structures of another. In order to avoid the unreasonable task of determining the separation of the structures span-by-span, a standard separation value should be used based on a worst case analysis. Thus if structures of one line do not always line up with the other, the separation determined above should be based on the assumption that the structure of one line is located next to the mid-span point of the line that has the most sag.

5.6.3 <u>Other Factors</u>: Galloping should also be taken into account in determining line separation. In fact, it may be the determining factor in line separation. See Chapter 6 for a discussion of galloping.

Standard phase spacing should also be taken into account. For example, if two lines of the same voltage using the same type structures and phase conductors are on a single ROW, a logical separation of the two closest phases of the two lines should be at least the standard phase separation of the structure.

5.6.4 <u>Altitude Greater than 1000 Meters (3300 Feet)</u>: If the altitude of the lines is greater than 1000 meters (3300 feet), see Section 23 of the NESC for additional separation requirements.

6. CLEARANCES BETWEEN CONDUCTORS AND BETWEEN CONDUCTORS AND OVERHEAD GROUND WIRES

6.1 General: The preliminary comments and assumptions of section 4.2, Chapter 4, also apply to this chapter.

This chapter considers those design limits related to conductor separation. It is assumed that only standard REA structures will be used, thus making it unnecessary to check conductor separation at structures. Therefore, the only separation values left to consider are those related to span length and conductor sags.

Any one of the following recommendations for conductor separation could be the limiting factor for span length. Other factors not covered in this chapter which may limit span length are structure strength, insulator strength, and ground clearance.

6.2 Maximum Span as Limited by Horizontal Conductor Separation: Sufficient horizontal separation between phases is necessary to prevent swinging contacts and flashovers between conductors where there is insufficient vertical separation.

6.2.1 Situations Under Which Maximum Span as Limited by Horizontal Separation Must be Met:

If the vertical separation at the structure (regardless of horizontal displacement) of phase conductors of the same or different circuit(s) is less than the appropriate value given in Table 6-1, then the requirements in sections 6.2.2, 6.2.3, and 6.2.4 below should be met.

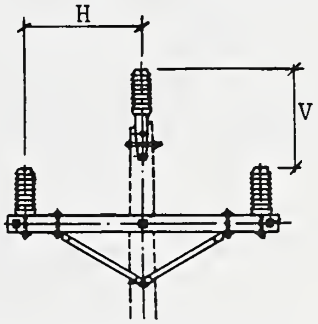


FIGURE 6-1: EXAMPLE OF VERTICAL AND HORIZONTAL SEPARATION VALUES.

6.2.2 Horizontal Separation Recommendations: The equations below give a sufficient horizontal phase spacing in relation to conductor sag, and thus indirectly to span length, in order to prevent swinging contacts or flashovers between phases of the same or different circuits.

$$H = (.00762)kV+F_c\sqrt{S_f(.3048)} + \ell_i(\sin\phi_{max})$$ (Metric) Eq. 6-1

$$H = (.025)kV+F_c\sqrt{S_f}+\ell_i(\sin\phi_{max})$$ (English) Eq. 6-2

TABLE 6-1

RECOMMENDED MINIMUM VERTICAL SEPARATION IN METERS (FEET)
BETWEEN PHASES OF THE SAME OR DIFFERENT CIRCUITS
NECESSARY FOR EQUATIONS 6-1 AND 6-2 NOT TO APPLY*

*(The values in this table are not recommended as minimum vertical separations at the structure for nonstandard structures, but are intended only to be used to determine whether or not horizontal separation calculations are required).

MINIMUM VERTICAL SEPARATION	Nominal Line-to-Line Voltage in kV					
	34.5-46	69	115	138	161	230
1. Phases of the Same Circuit	1.2 (4.0)	1.5 (4.8)	2.0 (6.4)	2.2 (7.2)	2.5 (8.0)	3.2 (10.4)
2. Phases of Different Circuits**	1.2 (4.0)	1.6 (5.1)	2.2 (7.0)	2.4 (8.0)	2.7 (8.9)	3.6 (11.7)
ALTITUDE CORRECTION TO BE ADDED TO VALUE IN NO. 2 ABOVE (NONE REQUIRED FOR NO. 1).						
Additional meters of clearance per 1000 meters of altitude above 1000 meters (same value also represents additional feet of clearance per 1000 feet of altitude above 3300 feet).	0	.03	.09	.12	.15	.23

**Assumes both circuits have the same nominal voltage. If they do not, the vertical separation can be determined using the equations below. See Section 23 of the NESC for altitude correction factors.

$$V = 1.2 + .0102(kV_{LG1} + kV_{LG2} - 50) \qquad \text{(Metric) Eq. 6-3}$$

$$V = 4ft. + \frac{.4}{12}(kV_{LG1} + kV_{LG2} - 50) \qquad \text{(English) Eq. 6-4}$$

where:

H = horizontal separation between the phase conductors at the structure in meters (feet).

kV = (for phases of the same circuit) the nominal line-to-line voltage in 1000's of volts for 34.5 and 46 kV and 1.05 times the nominal voltage in 1000's of volts for higher voltages.

kV = (for phases of different circuits) 1.05 times the magnitude of the voltage vector between the phases in 1000's of volts*. kV should never be less than 1.05 times the nominal line-to-ground voltage in 1000's of volts of the higher voltage circuit involved regardless of how the voltage vectors add up. It is recommended that if one is unsure of the vector relationship between the phases of different circuits, the voltage between the phases should be taken to be the sum of the two line-to-ground voltages, based on 1.05 times nominal voltage.

F_c = the experience factor.

ϕ max = the maximum 29 kPa (6 psf) insulator swing angle for the structure in question. See Chapter 7.

S_f = the final sag of the conductor at 16°C (60°F), no load, in meters (feet).

ℓ_i = the length of the insulator string in meters (feet), $\ell_i = 0$ for post or restrained suspension insulators.

V = vertical separation between phase conductors at the structure in meters (feet).

The experience factor (F_c) may vary from a minimum of .67 to a maximum of 1.4, depending upon how severe the wind and ice conditions are judged to be. The following are values of F_c that have in the past proved to be satisfactory.

F_c = 1.15 for the light loading zone
F_c = 1.2 for the medium loading zone
F_c = 1.25 for the heavy loading zone

Any value of F_c in the .67 to 1.4 range may be used if it is thought to be reasonable and prudent. There has been significant favorable experience with larger conductor sizes with horizontal spacing based on an F_c factor of .67; therefore, F_c factor values significantly less than the values listed above may be appropriate. If F_c values less than those given above are used, careful attention should be paid to galloping as a possible limiting condition on the maximum span length.

6.2.3 Additional Horizontal Separation Equation: The equation below, commonly known as the Percy Thomas formula, may be used in addition to (but not instead of) equations 6-1 and 6-2 for determining the horizontal separation between the phases at the structure. The equation takes into account the weight, diameter, sag, and span length of the conductor.

$$H = (.00762)kV + \frac{(E_c)(d_c)(S_p)}{w_c}(1.74) + \frac{\ell_i}{2}$$ (Metric) Eq. 6-5

$$H = (.025)kV + \frac{(E_c(d_c)(S_p)}{w_c} + \frac{\ell_i}{2}$$ (English) Eq. 6-6

where:

d_c = conductor diameter in millimeters (inches).
w_c = weight of conductor in N/m (lbs/ft.) (for standard gravity 1 kg = 9.81 N).
E_c = an experience factor. It is generally recommended that (E_c) be larger than 1.25.
S_p = sag of conductor at 16°C (60°F), expressed as a percent of span length.

All other symbols are as previously defined.

The Thomas equation may be used to examine the spacings of conductors on lines which have operated successfully in a locality by determining values of E_c. These values of E_c may be helpful in determining other safe spacings.

6.2.4 Maximum Span: Equations 6-1 and 6-2 can be rewritten and combined with equation 10-1 to yield the maximum allowable span, given the horizontal separation at the structure and the sag and length of the ruling span. (See Chapter 9 for a discussion of ruling span.)

$$L_{max} = \frac{(RS)}{(.552)}\left[\frac{H - (.00762)kV - \ell_i \sin\phi}{F_c\sqrt{S_{RS}}}\right]$$ (Metric) Eq. 6-7

$$L_{max} = (RS)\left[\frac{H - (.025)kV - \ell_i \sin\phi}{F_c\sqrt{S_{RS}}}\right]$$ (English) Eq. 6-8

where:

L_{max} = max. span as limited by conductor separation in meters (feet).
RS = length of ruling span in meters (feet).
S_{RS} = sag of the ruling span at 16°C (60°F) final sag in meters (feet).

Other symbols are as previously defined.

6.3 Maximum Span as Limited by Galloping:

6.3.1 The Galloping Phenomenon: Galloping, sometimes called dancing, is a phenomenon where the transmission line conductors vibrate with very large amplitudes. This may result in: (1) contact between phase conductors or between phase conductors and overhead ground wires, resulting in electrical outages and conductor burning, (2) conductor failure at support point due to the violent stress caused by galloping, (3) possible structure damage, and (4) excessive conductor sag due to the overstressing of conductors.

Galloping usually occurs only when a steady, moderate wind blows over a conductor covered by a layer of ice deposited by freezing rain, mist or sleet. The coating may vary from a very thin glaze on one side to a solid three-inch cover and may give the conductor a slightly out-of-round, elliptical, or quasi-airfoil shape. The wind blowing over this irregular shape results in aerodynamic lift which causes the conductor to gallop. The driving wind can be anything between 8 to 72 kilometers per hour (5 to 45 miles per hour) at an angle to the line of 10 to 90 degrees and may be unsteady in velocity or direction.

During galloping, the conductors oscillate elliptically at frequencies on the order of 1-Hz or less with vertical amplitudes of several feet. Sometimes two loops appear, superimposed on one basic loop. Single-loop galloping rarely occurs in spans over 190 to 215 meters (600 to 700 feet). This is fortunate since it would be impractical to provide clearances large enough in long spans

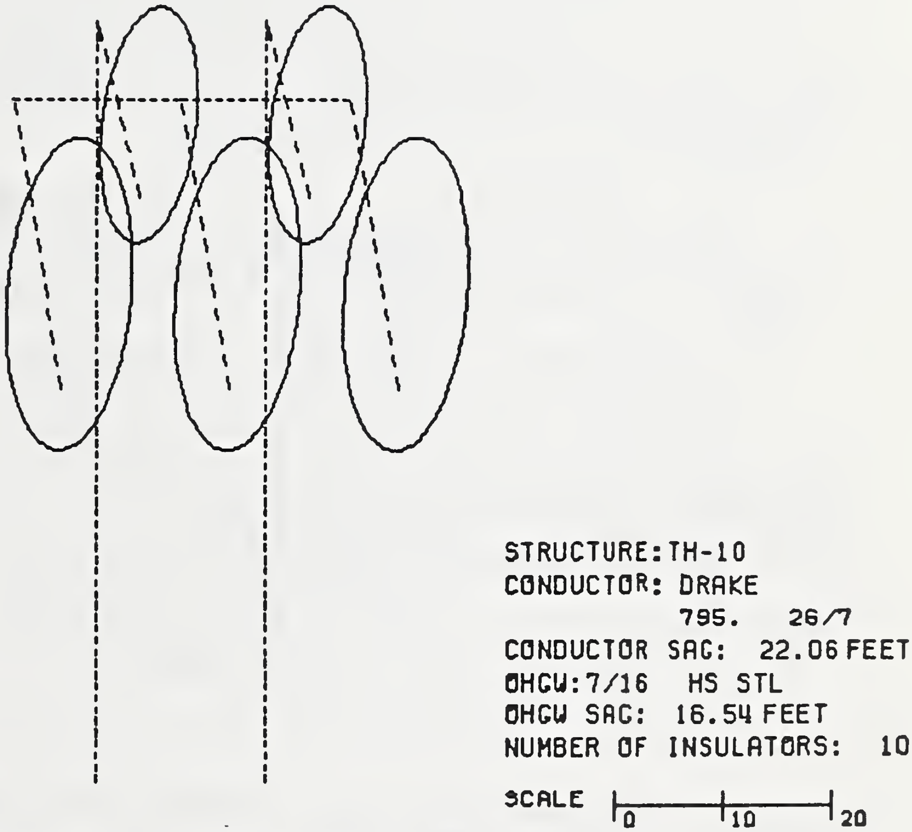
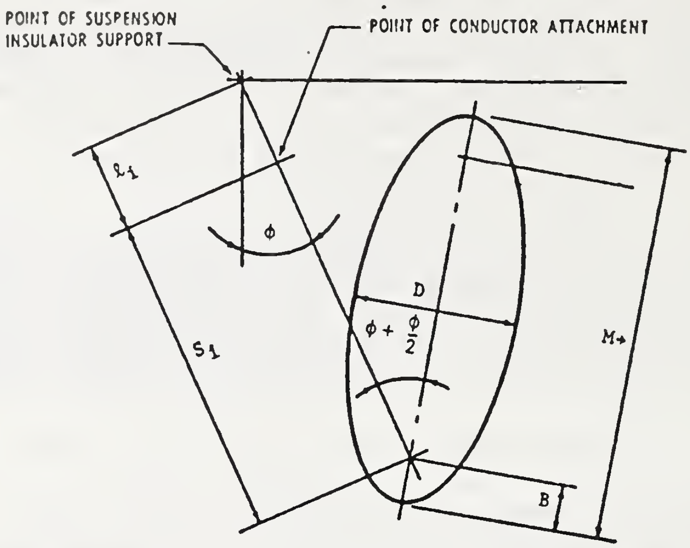


FIGURE 6-2: SINGLE LOOP
GALLOPING ANALYSIS

to prevent the possibility of contact between phases. In double-loop galloping, the maximum amplitude usually occurs at the quarter span points and is smaller than that resulting from single-loop galloping. There are several things that can be done at the design stage of a line to reduce potential conductor contacts caused by galloping, such as shorter spans, or increase phase separation. The H-frame structures provide very good phase spacing for reducing galloping contacts.

FIGURE 6-3: GUIDE FOR PREPARATION OF LISSAJOUS ELLIPSES



	Single Loop		Double Loop	
Angle "ϕ"	$\phi = \tan^{-1}\left(\frac{p_c}{w_c}\right)$			Eq. 6-9
Major Axis "M"	$M = 1.25\ S_i + .3048$	(Metric) Eq. 6-10	$M = .3048 + \sqrt{\frac{3a\left(L + \frac{8S_i^2}{3L} - 2a\right)}{8}}$	(Metric) Eq. 6-14
	$M = 1.25\ S_i + 1$	(English) Eq. 6-11	$M = 1 + \sqrt{\frac{3a\left(L + \frac{8S_i^2}{3L} - 2a\right)}{8}}$	(English) Eq. 6-15
			$a = \sqrt{\left(\frac{L}{2}\right)^2 + S_i^2}$	
Distance "B"	$B = .25\ S_i$	Eq. 6-12	$B = .2M$	Eq. 6-16
Minor Axis "D"	$D = .4M$	Eq. 6-13	$D = 1.104\sqrt{M - .3048}$	(Metric) Eq. 6-17
			$D = 2\sqrt{M - 1}$	(English) Eq. 6-18

where:

p_c = wind load per unit length on iced conductor in N/m (lbs/ft). Assume a .0958 kPa (2 psf) wind.
w_c = weight per unit length of conductor plus 12.7 mm (.5 in.) of radial ice in N/m (lbs/ft) (for standard gravity 1 kg = 9.81 N).
L = span length in meters (feet).
M = major axis of Lissajous ellipses in meters (feet).
S_i = final sag of conductor with 12.7 mm (.5 in.) of radial ice, no wind, at 0°C (32°F).
D = minor axis of Lissajous ellipses in meters (feet).
B, ϕ = are as defined in figure above.

6.3.2 Galloping Considerations in the Design of Transmission Lines: In areas where galloping is either historically known to occur or is expected, it should be taken into account in the design of the line. The primary tool for doing this is the Lissajous ellipses which give the theoretical envelope of a galloping conductor. To avoid contact between phase conductors or between phase conductors and overhead ground wires, their ellipses should not touch. However, depending upon how frequent and how severe the galloping is expected to be, there may be situations where allowing ellipses to overlap may be the best design choice when economics are considered.

6.4 Maximum Span as Limited by Conductor Separation Under Differential Ice Loading Conditions:

6.4.1 General: There is a tendency among conductors covered with ice, for the conductor closest to the ground to drop its ice first. There are two problems caused by this. First, upon unloading its ice, the lower conductor may jump up toward the upper conductor, possibly resulting in a temporary short circuit. Second, after the lower conductor recovers from its initial "jump up", it will settle into a position with less sag than before, which may persist for long periods of time. If the upper conductor has not dropped its ice, the reduced separation may result in a flashover between phases during a system disturbance.

The clearance recommendations given below are intended to insure that sufficient separation will be maintained during differential ice loading conditions with an approach towards providing clearance for the "ice jump".

6.4.2 Clearance Recommendations: The minimum distance between phase conductors, and between phase conductors and overhead ground wires under differential ice loading conditions are given in Table 6-2. Note that an additional .6 meter (2 feet) of clearance must be added to the values given in Table 6-2 when conductors or wires are directly over one another or have less than a .3 meter (1 foot) horizontal offset. The purpose of this requirement is to improve the performance of the line under ice jump conditions. It has been found that a horizontal offset of as little as .3 meter (1 foot) significantly lessens the ice jump problem. Figure 6-4 illustrates the manner in which the minimum distance is to be measured. Also indicated are the horizontal and vertical components of clearance and their relationship.

From Figure 6-4, it can be seen that the relationship of the clearance components are:

$$D_V = \sqrt{(SP)^2 - (H)^2} \qquad \text{Eq. 6-19}$$

where:

SP = minimum distance between conductors as required by Table 6-2.
D_V = vertical component of clearance.
H = horizontal component of clearance.

TABLE 6-2

RECOMMENDED MINIMUM SEPARATION IN ANY DIRECTION BETWEEN PHASE CONDUCTORS AND BETWEEN PHASE CONDUCTORS AND OVERHEAD GROUND WIRES IN METERS (FEET) UNDER DIFFERENTIAL ICE LOADING CONDITIONS

	Nominal Line-to-Line Voltage in kV_{LL}						
MINIMUM SEPARATION BETWEEN:	34.5	46	69	115	138	161	230
1. Phase conductors of the same circuit	.28 (.87)	.37 (1.2)	.56 (1.8)	.92 (3.0)	1.1 (3.6)	1.3 (4.2)	1.9 (6.0)
2. Phase conductors and overhead ground wires	.16 (.52)	.21 (.70)	.32 (1.0)	.55 (1.8)	.64 (2.1)	.77 (2.5)	1.1 (3.5)

If one conductor is located directly above another or has less than a .3 meter (1 foot) horizontal offset, .6 meter (2 feet) of clearance in addition to that specified in the table above must be maintained.

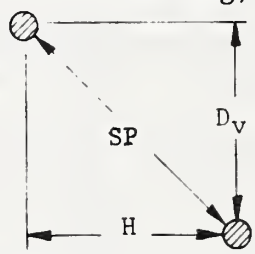


FIGURE 6-4: MINIMUM DISTANCE BETWEEN CONDUCTORS (SP)

6.4.3 <u>Conditions Under Which Clearances Apply</u>: Upper conductor at 0°C (32°F), final sag, with a radial thickness of ice equal to the maximum thickness of ice that can be reasonably expected for the geographical area in question. The lower conductor should be assumed to be at 0°C (32°F), final sag, no ice.

6.4.4 <u>Maximum Span</u>: For a structure with a given horizontal offset between phases, equation 6-19 can be used to determine what the vertical separation at the mid-span point must be in order to meet the total separation requirement. Since vertical separation is related to the relative sags of the phase conductors involved, and since sags are related to span length, a maximum span as limited by vertical separation can be determined. The formula for the maximum span as limited by vertical separation is:

$$L_{max} = (RS)\sqrt{\frac{D_u - B}{S_\ell - S_u}} \qquad \text{Eq. 6-20}$$

where:

L_{max} = maximum allowable span in meters (feet).
D_u = required vertical separation at mid-span in meters (feet).
B = vertical separation at supports in meters (feet).
S_ℓ = sag of lower conductor in meters (feet) without ice.
S_u = sag of upper conductor wire in meters (feet) with ice.
RS = ruling span in meters (feet).

6.5 <u>Overhead Ground Wire Sags and Clearances</u>: In addition to checking clearances between the OHGW and phase conductors under differential ice loading conditions, it is also important that the relative sags of the phase conductors and the OHGW be coordinated so that under more commonly occurring conditions, there will be a reasonably low chance of a mid-span flashover during a system disturbance. Adequate midspan separation is usually assured for standard REA structures by keeping the sag of the OHGW at 16°C (60°F) initial sag, no load conditions to 80 percent of the phase conductors under the same conditions.

6.6 <u>Clearance Between Conductors in a Crossarm to Vertical Construction Span</u>: Conductor contacts in spans changing from crossarm to vertical type construction may be reduced by proper phase arrangement and by limiting span lengths. Limiting span lengths well below the average span lengths is particularly important in areas where ice and sleet conditions can be expected to occur. See Figure 6-5.

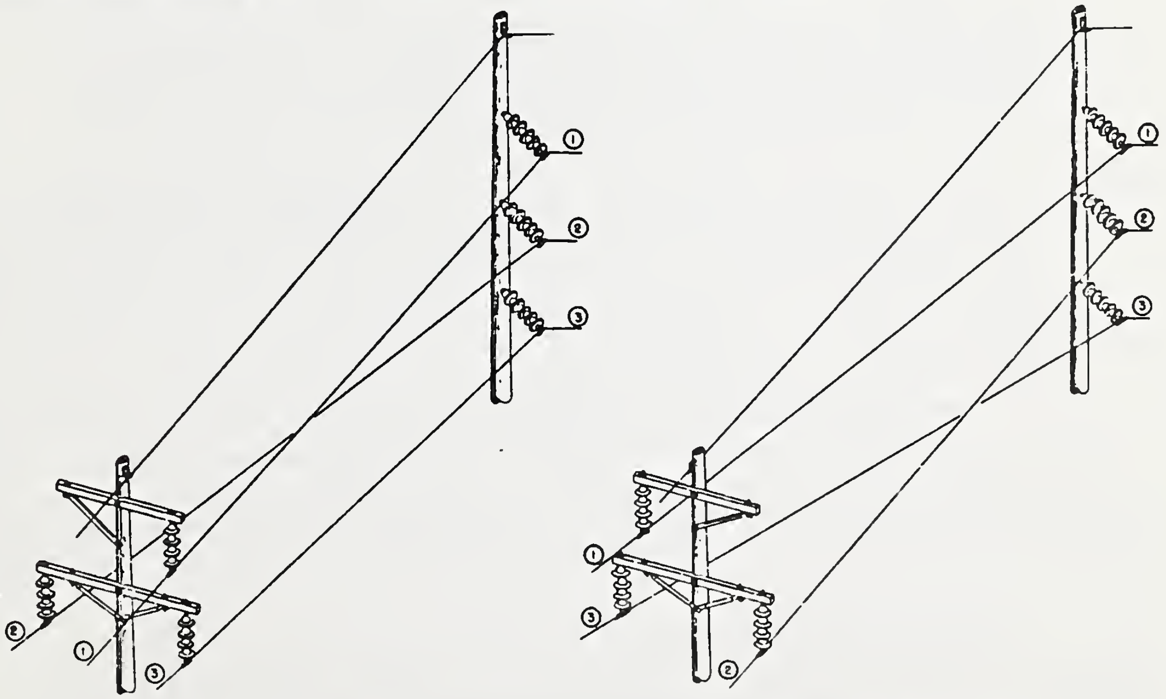


FIGURE 6-5: PROPER PHASE ARRANGEMENTS FOR CROSSARM TO VERTICAL CONSTRUCTION.

7. INSULATOR SWING AND CLEARANCES OF CONDUCTORS FROM SUPPORTING STRUCTURES

7.1 Introduction: Suspension insulator strings supporting transmission conductors, either at tangent or angle structures, are usually free to swing about their points of support. Therefore, it is necessary to insure that when the insulators do swing, reasonable clearances are maintained to structures and guy wires. The amount of swing varies with such factors as: conductor tension, temperature, wind velocity, and the ratio of the vertical to horizontal spans.

The purpose of this chapter is to explain how insulator swing application guides called swing charts are prepared. Chapter 10 explains how these charts are used in laying out a line.

7.2 Clearances and Their Application: Table 7-1 gives three sets of clearances that are suggested in order to insure proper separation between conductors and structures or guys under various conditions. Figure 7-1 illustrates the various situations in which the clearances are to be applied.

7.2.1 No Wind Clearance: This is the minimum clearance which should be maintained between the conductor and structure or guys under conditions that are expected to exist for long periods of time. It provides a balanced insulation system where the insulating value of the air gap is approximately the same as that of the insulator string (does not include extra insulators used at angle structures). Conditions at which clearance are to be maintained follow:

a. Wind: No wind shall be assumed to be blowing.

b. Temperature: A temperature of 16°C (60°F) is assumed with the conductor at its final sag condition. The engineer may also want to evaluate clearances at an extreme cold condition (such as -20°F initial sag) and an extreme hot condition (such as 167°F final sag).

7.2.2 Moderate Wind Clearance: This is the minimum clearance that should be maintained under conditions that are expected to occur occasionally. The air gap values given have a lower flashover value than that of the insulator string length normally used at the various voltages. This condition is acceptable because: (1) although the air gap flashover value is less than that of the insulator string, it is still quite high and should be sufficient to withstand most of the severe voltage stress situations, and (2) the clearances are to be maintained at conditions that are not expected to occur often. It should be pointed out that there are different clearance requirements to the structure than to anchor guys. Also, note that Table 7-1 requires that additional clearance must be provided if the altitude is above 1000 meters (3300 feet). Conditions at which clearances are to be maintained follow:

a. Wind: A wind of at least .29 kPa (6 psf) blowing in the direction shown in Figure 7-1 is assumed. Higher wind pressures can be used if judgment and experience deem it to be necessary. However, the use of excessively high wind values could result in a design that is overly restrictive and costly. It is recommended that wind

pressure values of no higher than .43 kPa (9 psf), 97 kph (60 mph) be used unless special circumstances exist.

b. Temperature: The temperature conditions at which the clearances are to be maintained depend upon the type of structure. For tangent and small angle structures where the insulator string is suspended from a crossarm, a temperature of no more than 0°C (32°F) should be used. A lower temperature value should be used where such a temperature can be reasonably expected to occur in conjunction with the wind value assumed. It should be borne in mind, however, that the insulator swing problem for this situation becomes worse as the temperature decreases. Therefore, in choosing a temperature lower than 0°C (32°F), one should weigh the increase in conservatism of line design against the increase or decrease in line cost.

For angle structures where the insulator string is dependent upon the force due to the change in direction of the conductor to hold it away from the structure, a temperature of 16°C (60°F) should be used. Even if the maximum conductor temperature is significantly greater than 16°C (60°F), a higher temperature need not be used as an assumed wind value of 64.5 kph (40 mph) (.29 kPa (6 psf)) has quite a cooling effect.

The conductor is assumed to be at final sag conditions for the 16°C (60°F) temperature and at the initial sag conditions for the 0°C (32°F).

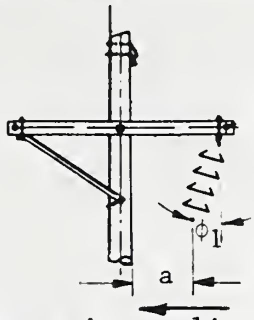
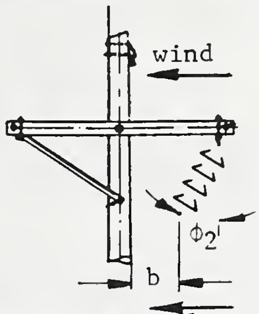
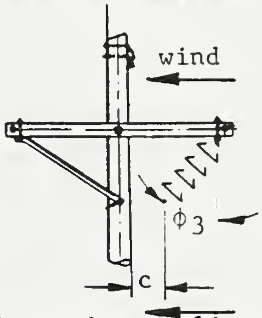
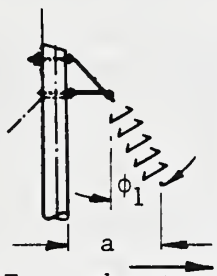
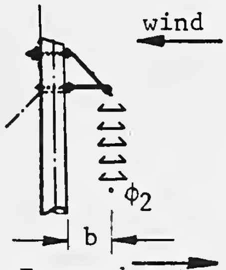
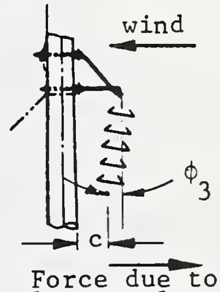
7.2.3 High Wind Clearance: This is the minimum clearance that should be maintained under high wind conditions that are expected to occur very rarely. The clearances provide enough of an air gap to withstand a 60 Hz flashover but not much more. The choice of such values is based on the philosophy that under the very rare high wind conditions, the line should not flashover due to the 60 Hz voltage. The conditions under which clearances are to be maintained follow:

a. Wind: The minimum assumed wind value should be at least the 10-year mean recurrence internal wind blowing in the direction shown in Figure 7-1. More wind may be assumed if deemed appropriate.

b. Temperature: The temperature assumed should be that temperature at which the extreme wind is expected to occur. The conductor should be assumed to be at final sag conditions.

7.3 Backswing: The combinations of wind direction and direction of force due to line angle that are usually the most severe and that govern insulator swing considerations are given in Figure 7-1. As can be seen, for angle structures where the insulator string is attached to the crossarm, the most severe condition is usually where the force of the wind and the force of the line angle are acting in the same direction. However, for those angle structures that are asymmetrical and the maximum insulator swing to the left is different than to the right, it is possible that the limiting swing condition may be when the wind force is in a direction opposite of that due to the force of the line angle. This would most likely occur where the line angle is small and tensions are low. This situation is called backswing, as it is a swing in a direction opposite of that in which the insulator is pulled by the line angle force. Figure 7-2 illustrates backswing.

FIGURE 7-1: ILLUSTRATION OF STRUCTURE INSULATOR SWING ANGLE LIMITS AND CONDITIONS* UNDER WHICH THEY APPLY (EXCLUDES BACKSWING)

	No Wind Insulator Swing	Moderate Wind Insulator Swing	High Wind Insulator Swing
TANGENT AND SMALL ANGLE STRUCTURES			
Conditions* at which clearances are to be maintained:	 Force due to line angle (if any).	 Force due to line angle (if any).	 Force due to line angle (if any).
Wind Force (F)	0	.29 kPa (6 lb/ft^2) minimum.	10 yr. mean wind, min. recommended value.
Temperature	16°C (60°F)	0°C (32°F) or <u>lower</u>	Temp. at which wind value is expected.
Conductor Condition	Final tension.	Initial tension.	Final tension.
MEDIUM AND LARGE ANGLE STRUCTURES			
Conditions* at which clearances are to be maintained:	 Force due to line angle.	 Force due to line angle.	 Force due to line angle.
Wind Force (F)	0	.29 kPa (6 lb/ft^2) minimum.	10 yr. mean wind, min. recommended value.
Temperature	16°C (60°F)	16°C (60°F)	Temp. at which wind value is expected.
Conductor Condition	Final tension.	Final tension.	Final tension.

a = No wind clearance.
b = Moderate wind clearance.
c = High wind clearance.

*See text for full explanation of conditions.

TABLE 7-1
RECOMMENDED MINIMUM CLEARANCES IN METERS (INCHES) AT
CONDUCTOR TO SURFACE OF STRUCTURE OR GUY WIRES*

	Nominal Line-to-Line Voltage in kV_{LL} Standard Number of 5-3/4" x 10" Insulators on Tangent Structures								
	34.5	46	69	115	138	161	230		
	3	3	4	7	8	10	12	13	14
NO WIND CLEARANCE									
Min. clearance to structure or guy at no wind in meters (inches) (A)(B)	.48 (19)	.48 (19)	.64 (25)	1.07 (42)	1.22 (48)	1.52 (60)	1.80 (71)	1.96 (77)	2.11 (83)
MODERATE WIND CLEARANCE (NESC)									
Min. clear. to structure at .29 kPa (6 psf) of wind in meters (in.)(C)(D)	.30 (12)	.30 (12)	.41 (16)	.66 (26)	.77 (30)	.89 (35)	1.27 (50)	1.32 (52)	1.42 (56)
Min. clearance to anchor guys at .29 kPa (6 psf) (C)(D)	.33 (13)	.40 (16)	.56 (22)	.88 (35)	1.04 (41)	1.19 (47)	1.65 (65)	1.65 (65)	1.65 (65)
HIGH WIND CLEARANCE									
Min. clearance to structure or guy at high wind in meters (inches)	.08 (3)	.08 (3)	.13 (5)	.25 (10)	.30 (12)	.36 (14)	.51 (20)	.51 (20)	.51 (20)

(A) If insulators in excess of the standard number for tangent structures are used, the no wind clearance value given should be increased by .15 m (6 in.) for each additional bell. If the excess insulators are needed for contamination purposes only, the additional clearance is not necessary.

(B) For post insulators, the no wind clearance to structure or guy is the length of the post insulator.

(C) More wind may be assumed if deemed necessary.

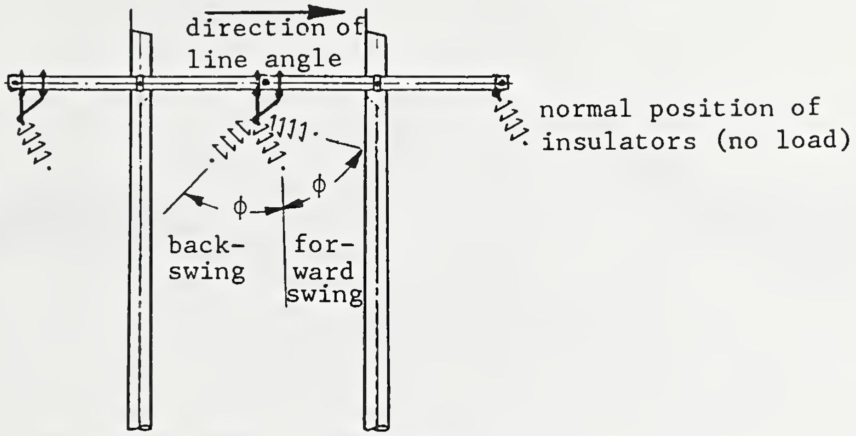
(D) The following values should be added as appropriate where the altitude exceeds 1000 meters (3300 feet).

		34.5-46	69	115	138	161	230
Additional mm of clearance per 300 m above 1000 m (additional in of clearance per 1000 ft. above 3300 feet)	Clearance to Structure	0	4 (.14)	12 (.43)	16 (.57)	20 (.72)	32 (1.2)
	Clearance to Anchor Guys	0	5 (.17)	15 (.53)	20 (.72)	25 (.89)	40 (1.4)

*Values are intended for wood structures only. For nonwooden structures, somewhat larger clearances may be appropriate.

When one is calculating backswing, one must assume those conditions that would tend to make the swing worse, which would be relatively low conductor tension. It is recommended that the temperature conditions given for large angle structures in Figure 7-1 be used, as they result in lower conductor tensions.

FIGURE 7-2: FORWARD AND BACKWARD SWING ANGLES

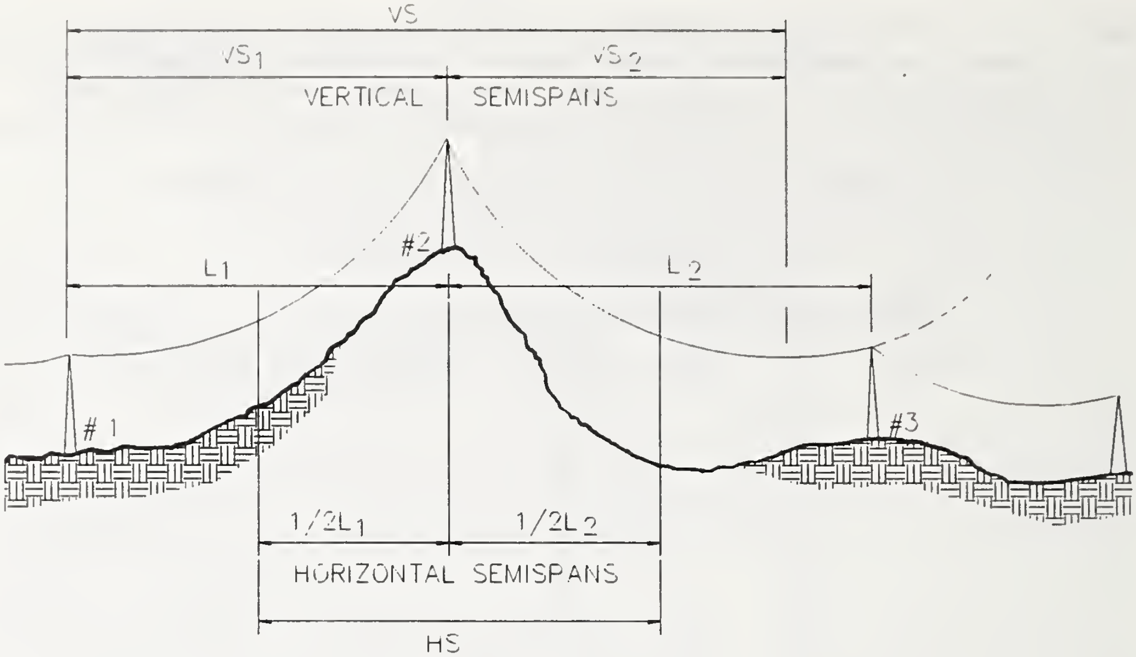


7.4 <u>Structure Insulator Swing Values</u>: Table 7-2 gives the allowable insulator swing values for some of the most often used standard REA tangent structures. These values represent the maximum angle from the vertical that an insulator string of the indicated number of standard bells may swing in toward the structure without violating the clearance category recommendation indicated at the top of each column. For tangent structures, the most restrictive angle for the particular clearance category for the entire structure is given. Thus, for an asymmetrical tangent structure (TS-1 for instance) where the allowable swing angle depends upon whether the insulators are assumed to be displaced to the right or left, the use of the most restrictive value means that the orientation of the structures with respect to the line angle need not be considered. For certain angle structures the insulator string has to be swung away from the structure in order to maintain the necessary clearance. These situations usually occur for large angle structures where the insulator string is attached directly to the pole or to a bracket on the pole and where the force due to the change in direction of the conductors is relied upon to hold the conductors away from the structure.

TABLE 7-2

INSULATOR SWING VALUES IN DEGREES
(For insulator string with ball hooks)

Structure and Voltage	Number of Insulators	No Wind Swing Angle	Mod. Wind Swing Angle	High Wind Swing Angle
69 kV				
TS-1, TS-1X	4	21.3	41.4	74.9
TSZ-1, TSZ-2	4	41.7	61.2	82.6
TH-1, TH-1G	4	35.6	61.2	85.6
115 kV - TH-1A	7	28.3	58.7	80.8
161 kV - TH-10	10	16.4	53.2	77.7
230 kV - TH-230	12	16.5	47.8	74.8



L = span,

L_1 - span from structure 1 to 2
L_2 = span from structure 2 to 3

HS = horizontal span
VS = vertical span

Span

Span is the horizontal distance from one structure to an adjacent structure along the line.

Vertical Span

The vertical span (sometimes called the weight span) is the horizontal distance between the maximum sag points of two adjacent spans. The maximum sag point of a span may actually fall outside the span. The vertical span lengths times the weight of the loaded conductor per foot will yield the vertical force per conductor bearing down upon the structure and insulators.

Horizontal Span

The horizontal span (sometimes called the wind span) is the horizontal distance between the mid-span points of adjacent spans. Thus, twice the horizontal span is equal to the sum of the adjacent spans. The horizontal span length times the wind force per foot on the conductor will yield the total horizontal force per conductor on the insulators and structure.

FIGURE 7-3: HORIZONTAL AND VERTICAL SPANS

7.5 Line design and structure clearances: The key effect which insulator swing has on line design is that it determines acceptable horizontal to vertical span ratios. Assuming that under a given set of wind and temperature conditions an insulator string on a structure may swing in toward the structure a given number of degrees, the angle can be related to a ratio of horizontal to vertical forces on the insulator string. This, in turn, can be related to a relationship between the horizontal span, the vertical span, and if applicable, the line angle.

For convenience sake, the acceptable limits of horizontal to vertical span ratios are plotted on a chart called an insulator swing chart. This chart can be easily used for checking or plotting out plan and profile sheets. Figures 7-4 and 7-5 show simplified insulator swing charts (for one swing condition only). It should be pointed out that there is one significant difference between the two charts. While for the chart in Figure 7-4 the greater the vertical span is for a fixed horizontal span the better off we are; the reverse is true for the chart of Figure 7-5. This is because the swing chart in Figure 7-5 is for a large angle structure where the force of the line angle is used to pull the insulator string away from the structure so that the less vertical force we have, the greater the horizontal span can be. The no wind insulator swing criteria will not be a limiting condition on tangent structures as long as there is no angle turned. If an angle is turned, it is possible that the no wind condition might control. The other two criteria may control under any circumstance. However, the high wind criteria will only be significant in those areas where unusually high winds can be expected.

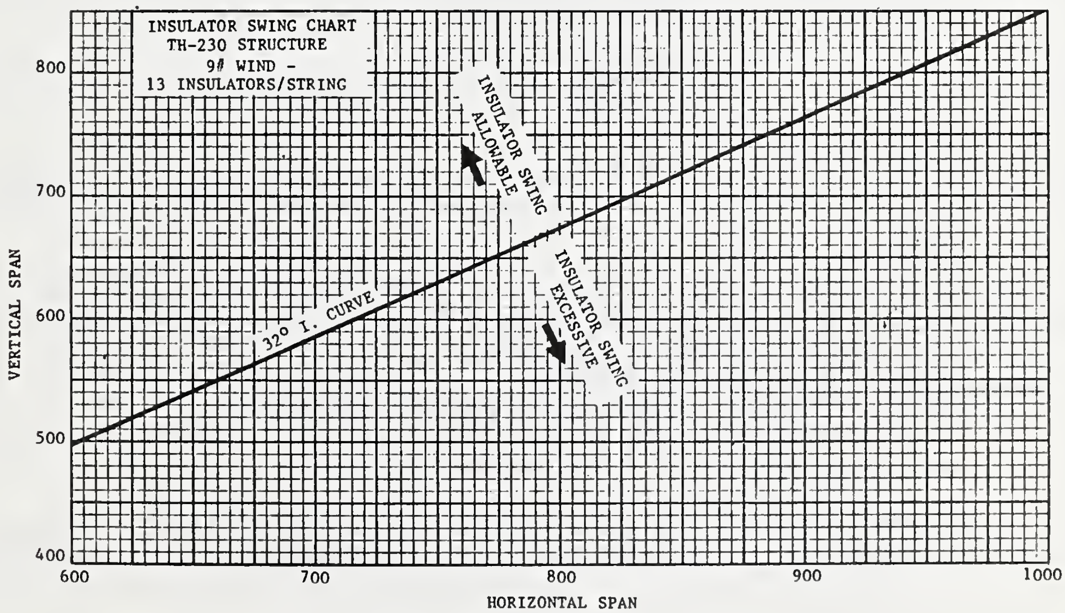


FIGURE 7-4: TYPICAL INSULATOR SWING CHART FOR A TANGENT STRUCTURE (Moderate Wind Swing Condition Only, No Line Angle Assumed)

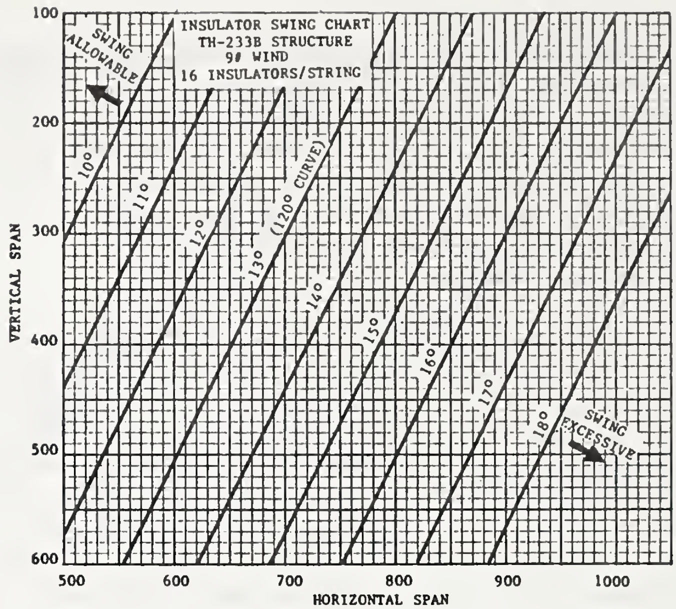


FIGURE 7-5: TYPICAL INSULATOR SWING CHART FOR A LARGE ANGLE STRUCTURE

7.6 Formulae for Insulator Swing: The following general formulae can be used to determine the angle of insulator swing that will occur under a given set of conditions for either tangent or angle structures.

$$\tan \phi = \frac{(2)(T)(\sin 1/2\Theta)+(HS)(p_c)}{(VS)(w_c)+(1/2)(W_i)} \qquad \text{Eq. 7-1}$$

$$p_c = \frac{(d_c)(F)}{1000} \qquad \text{(Metric) Eq. 7-2}$$

$$p_c = \frac{(d_c)(F)}{12} \qquad \text{(English) Eq. 7-3}$$

where:

ϕ = angle with the vertical through which the insulator string swings, in degrees.
Θ = line angle, in degrees.
T = conductor tension, in Newtons (pounds).
HS = horizontal span, in meters (feet).
VS = vertical span, in meters (feet).
p_c = wind load per unit length of bare conductor in Newtons per meter (pounds per foot).
w_c = weight per unit length of bare conductor in Newtons per meter (pounds per foot).
W_i = weight of insulator string (wind pressure neglected), in Newtons (pounds). (See Appendix C for insulator string weights).
d_c = conductor diameter in millimeters (inches).
F = wind force in Pa (lbs/ft^2).

In order for Formula 7-1 to be used properly, the following sign conventions must be followed:

Condition	Sign Assumed
o Wind:	
Blowing insulator toward structure	+
o "(2)(T)(sin 1/2Θ)" term (force on insulator due to line angle):	
Pulling insulator toward structure	+
Pulling insulator away from structure	-
o Insulator swing angle ϕ:	
Angle measured from a vertical line through point of insulator support in toward structure	+
Angle measured from a vertical line through point of insulator support away from structure	-

7.7 Insulator Swing Charts: Insulator swing charts similar to those in Figures 7-4 and 7-5 can be computed by using the formula below and the maximum angle of insulator swing values as limited by clearance to structure.

$$VS = \frac{(2)(T)(\sin 1/2\Theta)+(HS)(p_c)}{(w_c)(\tan\phi)} - \frac{Wi}{(2)(w_c)} \qquad \text{Eq. 7-4}$$

The symbols and sign conditions are the same as those given for Equation 7-1. Equation 7-4 above is Equation 7-1 solved for VS.

There is one situation where the equation above will yield an erroneous result. This is when the sign of the "(2)(T)(sin 1/2Θ) + (HS)(p_c)" term is different from the sign of the angle, when the standard sign conventions above are used. What is happening is the net horizontal force is in a direction opposite of that in which the insulator must swing. When such a situation occurs, it is a relatively simple matter of judgment what is in fact acceptable.

7.8 Excessive Angles of Insulator Swing: If upon spotting a line, a structure has excessive insulator swing, one or more of the steps outlined in section 10.4 of Chapter 10 may be required.

7.9 Example: For the tangent structure, develop the insulator swing chart. Assume that it is desired to turn slight angles with the tangent structure and the insulator string assembly uses the ball hook.

7.9.1 Given:

a. Voltage: 161 kV
Structure: TH-10
Conductor: 795 kcmil 26/7 ACSR
Insulation: Standard (10 bells)

b. NESC heavy loading district
High winds - .599 kPa (12.5 psf)
R.S.: 244 m (800 ft.)

c. Conductor Tensions

.29 kPa (6 psf) wind
-17.7°C (0°F)
27,775 N (6,244 lbs.) initial tension

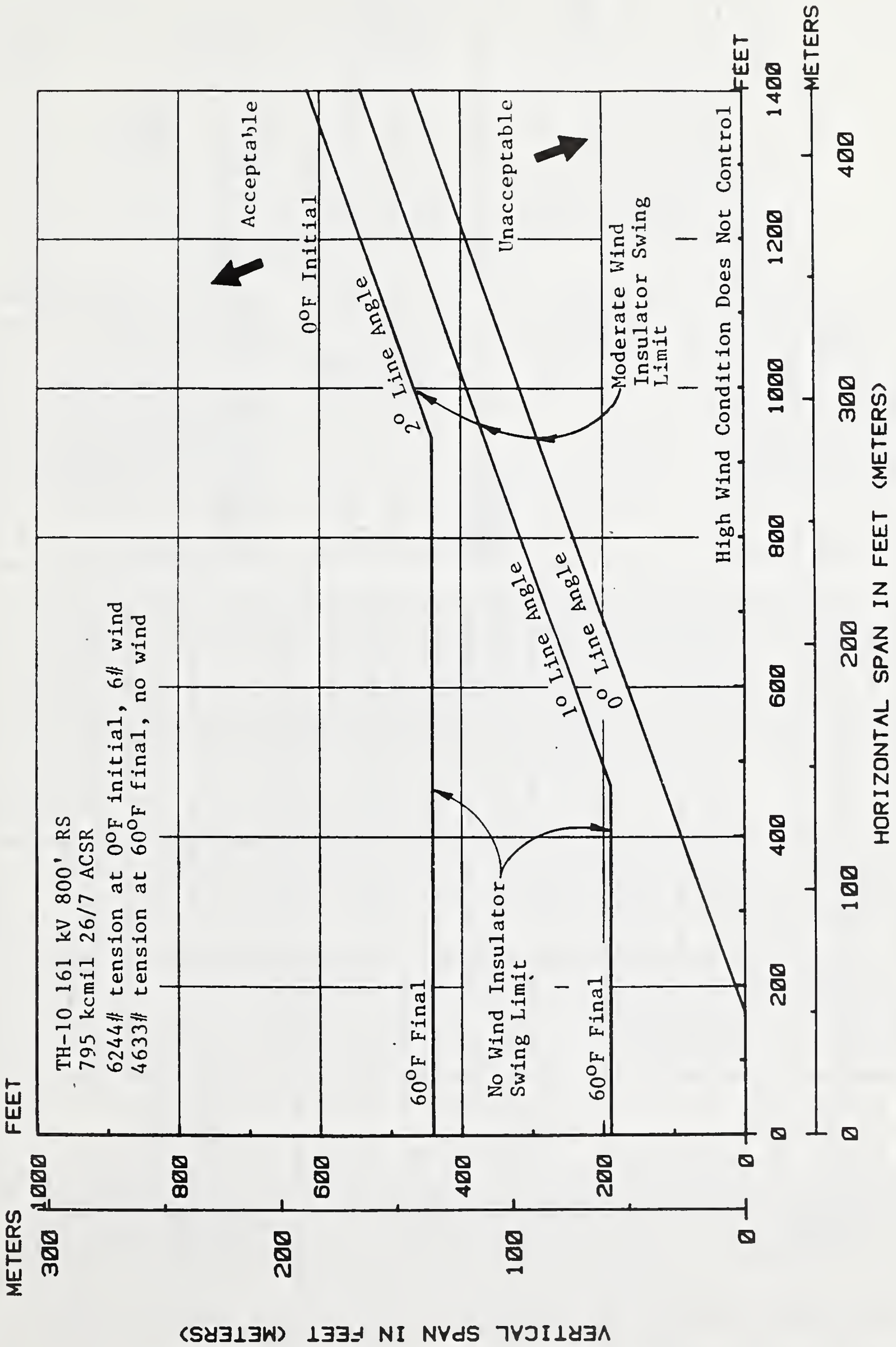
No wind
15.6°C (60°F)
20,608.6 N (4,633 lbs.) final tension

.599 kPa (12 psf) wind
0°C (32°F)
46,261.5 N (10,400 lbs.) final tension

7.9.2 Solution: Using the information on conductor sizes and weights, allowable swing angles, and insulator string weights from the appendices, the following calculation tables and the swing chart in Figure 7-6 can be determined.

Note that the high wind condition does not control, but that for some conditions, when angles are turned, the no wind condition does control.

FIGURE 7-6: INSULATOR SWING CHART FOR EXAMPLE 7-8



INSULATOR SWING CALCULATIONS

$$VS = \frac{\pm(2)(T)(\sin\theta/2) + (HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

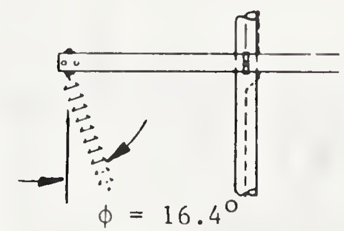
	θ	1°	2°		
	sin θ/2	.008727	.017452		
a)	(2)(T)(sin θ/2)	80.86	161.71		
b)	(HS)(p_c)	0	0		
	(a + b)	80.86	161.71		
c)	(w_c)(tan φ)	.32	.32		
d)	(a + b)/c	251.13	502.25		
e)	W_i/(2)(w_c)	61.70	61.70		
	d − e = VS	189.43	440.55		

	θ				
	sin θ/2				
a)	(2)(T)(sin θ/2)				
b)	(HS)(p_c)				
	(a + b)				
c)	(w_c)(tan φ)				
d)	(a + b)/c				
e)	W_i/(2)(w_c)				
	d − e = VS				

	θ				
	sin θ/2				
a)	(2)(T)(sin θ/2)				
b)	(HS)(p_c)				
	(a + b)				
c)	(w_c)(tan φ)				
d)	(a + b)/c				
e)	W_i/(2)(w_c)				
	d − e = VS				

Note: For the no wind case, vertical span is independent of horizontal span. It is only dependent upon line angle.

ϕ = angle with the vertical through which insulator string swings.
θ = line angle.
T = conductor tension.
HS = horizontal span.
VS = vertical span.
p_c = wind load on conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



SKETCH

Structure TH-10 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L,M,H)

Voltage 161 kV No. of Insulators 10

Type of Insulator Swing no wind

0 (F) lbs. Wind 60 °F

Cond. Dia. (d) 1.108

ϕ = 16.4°
p_c = 0 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 4,633 lbs.
W_i = 135 lbs.

$$p_c = \frac{(d)(F)}{12}$$

INSULATOR SWING CALCULATIONS

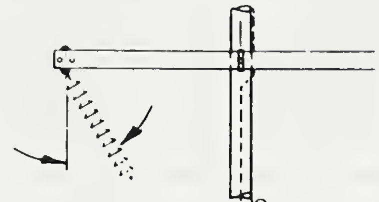
$$VS = \frac{\pm(2)(T)(\sin\theta/2) + (HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

$\theta = 0^o$	HS=200	HS=400	HS=800	HS=1000
$\sin\theta/2$	0	0	0	0
a) $(2)(T)(\sin\theta/2)$	0	0	0	0
b) $(HS)(p_c)$	110.80	221.60	443.20	554.00
$(a + b)$	110.80	221.60	443.20	554.00
c) $(w_c)(\tan\phi)$	1.460	1.460	1.460	1.460
d) $(a+b)/c$	75.77	151.53	303.07	378.83
e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
d - e = VS	14.07	89.83	241.37	317.13

$\theta = 1^o$	HS=200	HS=400	HS=800	HS=1000
$\sin\theta/2$	.008727	.008727	.008727	.008727
a) $(2)(T)(\sin\theta/2)$	108.98	108.98	108.98	108.98
b) $(HS)(p_c)$	110.80	221.60	443.20	554.00
$(a + b)$	219.78	330.58	552.18	662.98
c) $(w_c)(\tan\phi)$	1.460	1.460	1.460	1.460
d) $(a+b)/c$	150.29	226.05	377.59	453.35
e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
d - e = VS	88.59	164.35	315.89	391.65

$\theta = 2^o$	HS=200	HS=400	HS=800	HS=1000
$\sin\theta/2$	.017452	.017452	.017452	.017452
a) $(2)(T)(\sin\theta/2)$	217.95	217.95	217.95	217.95
b) $(HS)(p_c)$	110.80	221.60	443.20	554.00
$(a + b)$	328.75	439.55	661.15	771.95
c) $(w_c)(\tan\phi)$	1.460	1.460	1.460	1.460
d) $(a+b)/c$	224.80	300.57	452.10	527.87
e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
d - e = VS	163.10	238.87	390.40	466.17

ϕ = angle with the vertical through which insulator string swings.
θ = line angle.
T = conductor tension.
HS = horizontal span.
VS = vertical span.
p_c = wind load on conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



$\phi = 53.2^o$

SKETCH

Structure TH-10 Ruling Span 800 ft.
Conductor 795 26/7 ACSR Loading Dist. (L,M,H)
Voltage 161 kV No. of Insulators 10
Type of Insulator Swing Moderate wind
6 (F) lbs. Wind 0 °F
Cond. Dia. (d) 1.108

ϕ = 53.2 °
p_c = .554 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 6,244 lbs.
W_i = 135 lbs.

$$p_c = \frac{(d)(F)}{12}$$

INSULATOR SWING CALCULATIONS

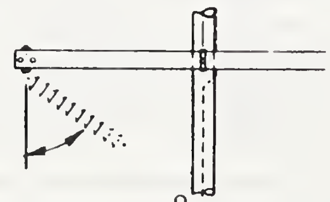
$$VS = \frac{\pm(2)(T)(\sin\theta/2) + (HS)(p_c)}{(w_c)(\tan\phi)} - \frac{W_i}{(2)(w_c)}$$

		HS=200	HS=400	HS=800	HS=1000
$\theta = 0^o$	$\theta = 0^o$				
	$\sin\theta/2$	0	0	0	0
	a) $(2)(T)(\sin\theta/2)$	0	0	0	0
	b) $(HS)(p_c)$	230.80	461.60	923.20	1154.00
	$(a + b)$	230.80	461.60	923.20	1154.00
	c) $(w_c)(\tan\phi)$	5.02	5.02	5.02	5.02
	d) $(a+b)/c$	46.00	92.00	183.99	229.99
	e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
	$d - e = VS$	-15.70	30.30	122.29	168.29

		HS=200	HS=400	HS=800	HS=1000
$\theta = 1^o$	$\theta = 1^o$				
	$\sin\theta/2$	.008727	.008727	.008727	.008727
	a) $(2)(T)(\sin\theta/2)$	181,51	181.51	181.51	181.51
	b) $(HS)(p_c)$	230.80	461.60	923.20	1154.00
	$(a + b)$	412.31	643.11	1104.71	1335.51
	c) $(w_c)(\tan\phi)$	5.02	5.02	5.02	5.02
	d) $(a+b)/c$	82.17	128.17	220.17	266.17
	e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
	$d - e = VS$	20.47	66.47	158.47	204.47

		HS=200	HS=400	HS=800	HS=1000
$\theta = 2^o$	$\theta = 2^o$				
	$\sin\theta/2$	.017452	.017452	.017452	.017452
	a) $(2)(T)(\sin\theta/2)$	363.01	363.01	363.01	363.01
	b) $(HS)(p_c)$	230.80	461.60	923.20	1154.00
	$(a + b)$	593.81	824.61	1286.21	1517.01
	c) $(w_c)(\tan\phi)$	5.02	5.02	5.02	5.02
	d) $(a+b)/c$	118.35	164.35	256.34	302.34
	e) $W_i/(2)(w_c)$	61.70	61.70	61.70	61.70
	$d - e = VS$	56.65	102.65	194.64	240.64

ϕ = angle with the vertical through which insulator string swings.
θ = line angle.
T = conductor tension.
HS = horizontal span.
VS = vertical span.
p_c = wind load on conductor/ft.
w_c = weight of conductor/ft.
W_i = weight of insulator string.



$\phi = 77.7^o$

SKETCH

Structure TH-10 Ruling Span 800 ft.

Conductor 795 26/7 ACSR Loading Dist. (L,M,H)

Voltage 161 kV No. of Insulators 10

Type of Insulator Swing high wind

12.5 (F) lbs. Wind 32 ^oF

Cond. Dia. (d) 1.108

ϕ = 77.7 ^{o}
p_c = 1.154 lbs/ft.
w_c = 1.0940 lbs/ft.
T = 10,400 lbs.
W_i = 135 lbs.

$$p_c = \frac{(d)(F)}{12}$$

8. INSULATION AND INSULATORS

8.1 <u>Insulator Types</u>: The two main types of insulators used on transmission lines are suspension bells and pin/post units. Several suspension units are connected in a string to achieve the insulation level desired. With post insulators, a single unit with the desired rating is used. See Figures 8-1 and 8-2.

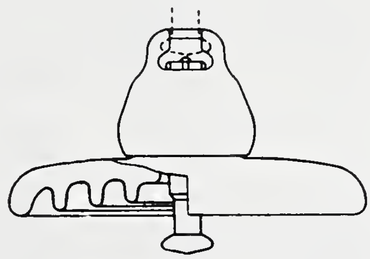


FIGURE 8-1: A STANDARD SUSPENSION BELL

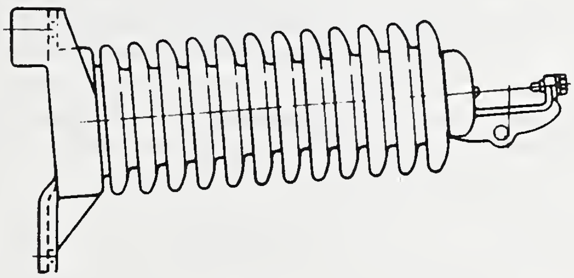


FIGURE 8-2: A TYPICAL HORIZONTAL POST INSULATOR (FOR 69 kV LINES)

8.2 <u>Insulation Levels Using Suspension Bells</u>: Given below are suggested REA insulation levels. Under certain special circumstances as discussed in subsequent sections, more insulation may be warranted.

8.2.1 <u>Tangent and Small Angles</u>: Table 8-1 indicates the recommended number of 5-3/4 x 10" suspension insulators to be used per phase on wood tangent and small angle structures. Also given are the electrical characteristics of the insulator strings.

8.2.2 <u>Angles</u>: For angle structures where the conductor tension is depended upon to pull the insulator string away from the structure, one more insulator bell than used on tangent structures should be used. The sole exception to this is 34.5 kV where no additional bells are used.

TABLE 8-1

RECOMMENDED REA INSULATION LEVELS
(SUSPENSION AT TANGENT
AND SMALL ANGLE STRUCTURES)

Flashover Characteristics in kV

Nominal L-L Voltage in kV	No. of 5-3/4x10" Bells	60 Hz Low Freq. Dry	60 Hz Low Freq. Wet	Impulse Pos.	Impulse Neg.	Total Leakage Distance in m (in.)
34.5	3	215	130	355	340	.876 (34.5)
46	3	215	130	355	340	.876 (34.5)
69	4	270	170	440	415	1.17 (46)
115	7	435	295	695	670	2.04 (80.5)
138	8	485	335	780	760	2.34 (92)
161	10	590	415	945	930	2.92 (115)
230	12	690	490	1105	1105	3.51 (138)

8.2.3 Deadends: In situations where the insulator string is in line with the conductor, the number of bells should be two more than what was used for tangent structures. This situation occurs at large angles, and tangent deadends where the conductor is deadended on to an insulator string. The sole exception to this is 34.5 kV where one additional bell is used.

8.3 Insulation Levels Using Post Insulators: Given below are electrical characteristics for horizontal post insulators that are recommended on REA systems.

TABLE 8-2

RECOMMENDED REA INSULATION LEVELS
(POSTS AT TANGENT AND SMALL ANGLE STRUCTURES)

Flashover Characteristics in kV

L-L kV	60 Hz Low Freq. Dry	60 Hz Low Freq. Wet	Impulse Pos.	Impulse Neg.	Total Leakage Distance in m (in.)
34.5	125	115	210	260	.73 (29)
46	150	135	255	344	1.02 (40)
69	200	180	330	425	1.35 (53)
115	380	330	610	780	2.54 (100)
138	430	390	690	870	2.79 (110)

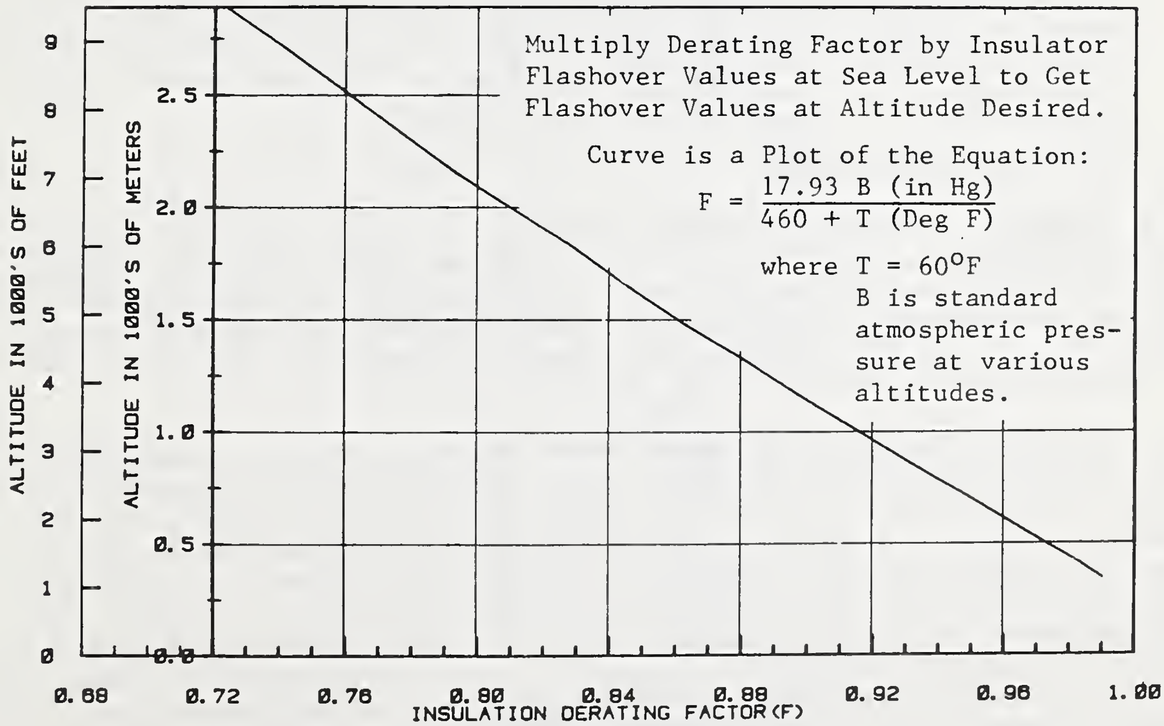
8.4 Electrical Characteristics of Insulators: Low frequency dry flashover ratings are generally the most common flashover values referred to when comparing insulators because these values can be tested easily and accurately. However, this rating is probably the least significant of the electrical characteristics of an insulator as flashover (60 Hz) of an insulator in service almost never occurs under normal dry operating conditions. When comparing different types of insulators (e.g. post vs suspension), the other characteristics such as impulse and wet flashover do not necessarily follow the same pattern as the low frequency dry flashover ratings. Since for voltages up to 230 kV the most severe stress on the insulation is usually caused by lightning, the most important flashover characteristic is the impulse flashover values as the wave shape used to make the test most closely imitates the shape of a lightning surge.

8.5 High Altitude Considerations

8.5.1 General: As altitude increases, the insulation value of air decreases so that an insulator at a high elevation will flash over at a lower voltage than the same insulator at sea level. Figure 8-3 below gives the derating factors for insulator flashover values as a function of altitude. The derating factors apply to both the low frequency flashover values and the impulse flashover values.

FIGURE 8-3

INSULATION DERATING FACTOR
vs. ALTITUDE IN 1,000's OF
METERS (FEET) (230 kV AND BELOW)



For example, if the low frequency dry flashover value of seven standard insulator bells is 435 kV, then at an altitude of 1800 meters (6000 feet), it will be 435 kV x .827 = 360 kV (where .827 is obtained from Figure 8-3). In addition to increasing the number of insulators for high altitude, it is also necessary to increase the structure air gap clearances. This could result in either a decreased allowable insulator swing angle or a longer crossarm (see Chapter 7 for details).

8.5.2 Insulation For Lines With Relatively Small Changes in Altitude: When the insulation derating factor for the line altitude is at a value less than approximately 90 percent of the insulation value at sea level (see Figure 8-3), then additional insulation should be added to bring the insulation level up to at least 90 percent of the sea level value.

8.5.3 Insulation For Lines With Significant Elevation Changes But Less Than 1500 Meters (5000 Feet): If the elevation change in a line from its low point to its highest point is less than 1500 meters (5000 feet), it is recommended that insulation for the entire length of the line be based on the weighted average altitude of the line by applying the procedure given in 8.5.2 above to that altitude.

8.5.4 Insulation for Line With Elevation Changes Greater than 1500 Meters (5000 Feet): Where the elevation change is greater than 1500 meters (5000 feet), the following two steps should be taken:

a. The entire line insulation should be upgraded for the minimum altitude of the line using the procedure in paragraph 8.5.2 above.

b. In sections of line where the altitude of the line increases to the point where the insulation value is less than approximately 90 percent of the insulation value at the minimum line altitude, additional insulation should be used in that section. Thus on the same line there may be different numbers of insulator bells at different points along its length.

8.6 Lightning Considerations

8.6.1 General: Transmission lines are subjected to three types of voltage stress that may cause flashover of the insulation: power frequency voltage, switching surges, and lightning surges. Flashovers due to power frequency voltages are primarily a problem in contaminated conditions and are discussed in section 8.7. Of the remaining two causes of flashovers, lightning is the more severe for lines of 230 kV and below.

8.6.2 Lightning Flashover Mechanism: When lightning strikes a transmission line, it can either hit the overhead ground wire or the phase conductors. If a phase conductor is hit, there will almost certainly be a flashover of the insulation. Thus to avoid this near certainty of a flashover, an overhead ground wire (OHGW) is used to intercept the lightning strokes. To prevent a shielding failure, the shielding angle, should be kept at 30° or less. The shielding angle is the angle measured from the vertical between the OHGW and the phase conductors, as shown in Figure 8.4. On H-frame structures where two overhead ground wires are used, the center phase may be considered to be properly shielded even if the shielding angle to it is greater than 30°. For

structures whose height is in excess of 28 meters (92 feet), shielding angles of less than 30° as indicated in Table 8-3 should be used. Where there is an unusually high exposure to lightning, such as at river crossings, an even smaller shielding angle may be warranted.

TABLE 8-3

REDUCED SHIELDING ANGLE VALUES

Structure Height in Meters (Feet)	Recommended Shielding Angle in Degrees
28 (92)	30
30 (99)	26
35 (116)	21

If lightning strikes an overhead ground wire, a traveling current wave will be set up which will in turn induce a traveling voltage wave. This voltage wave will generally increase in magnitude as it travels down the wire until it reaches a structure where the reflection of the traveling wave from the ground (the OHGW is grounded at every structure) will prevent the voltage from increasing further. If the traveling voltage wave at the structure is sufficiently high, a "back flashover" across the insulation from the ground wire or overhead ground wire to the phase conductor will occur. The factors that determine if a back flashover will occur are the amount of insulation, the footing resistance (for the higher the footing resistance, the higher the voltage rise at the structure), and the span length.

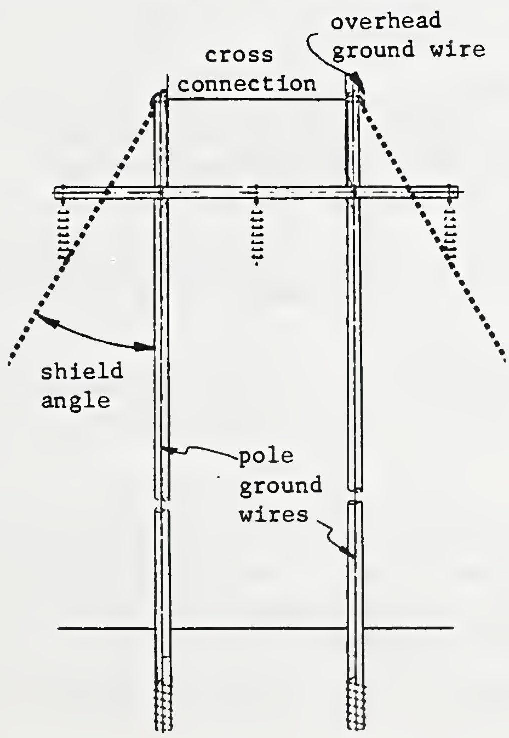


FIGURE 8-4: SHIELDING ANGLE AND POLE AND OVERHEAD GROUND WIRES

8.6.3 Designing for Lightning: An overhead ground wire should be used in all locations where the isokeraunic level is above 20. The overhead ground wire should be grounded at every structure by way of a structure ground wire. At H-frame structures, the OHGW's should each be connected to a structure ground wire and to one another so that if one structure ground wire breaks, both overhead ground wires will still be grounded.

In areas where the isokeraunic level is 20 or less, an overhead ground wire should still be used for a distance of .8 kilometer (.5 mile) out of a substation.

For wood structures, the REA recommended REA levels of insulation have historically provided satisfactory performance. Under unusual conditions, extra insulation may have to be considered.

If wood structures with steel arms or all steel structures are used in areas where there is a high isokeraunic level, consideration should be given to using one additional suspension bell beyond the standard REA insulation levels.

8.6.4 Footing Resistance: For satisfactory lightning performance of a line, low footing resistance is essential. Exactly what value of footing resistance is acceptable or unacceptable is not a simple matter as it depends upon several variables. Previous successful experience with a similar line in similar circumstances can be one guide. The following may be useful in determining what lightning outage rate a given footing resistance would yield.

(a) Transmission Line Reference Book, 345 kV and Above, Palo Alto, Calif., Electric Power Research Institute, 1975.

(b) "Estimating Lightning Performance of Transmission Lines," J. M. Clayton and F. S. Young. IEEE Transactions on Power Apparatus and Systems, November 1964, pp. 1102-1110.

A lightning outage rate of 1 to 4 per 160 km (100 miles) per year is acceptable with the lower number more appropriate for lines in the 161 to 230 kV range.

Generally, experience has shown that the footing resistance of individual structures of the line especially within .8 kilometer (.5 mile) of the substation should be less than 30 ohms.

It is recommended that as a line is built that the footing resistance of the ground connection be measured and recorded on a spot check basis. If footing resistance problems are expected, more readings should be made. If experience indicates that the lightning outage rate is not acceptable, these readings can be useful in taking remedial measures.

Footing resistance should not be taken immediately after a rain when the soil is moist.

If the footing resistance is higher than desired, driven rods may be used to reduce it. If the earth's resistivity is very high, counterpoise rather than driven rods may be required. See reference (b) above for guidance in the selection of counterpoise.

8.7 Contamination Considerations: If a line is to be built near a seacoast, an industrial district, or at other locales where airborne contaminants may build up on insulators, the problem of contamination induced flashovers should be considered.

8.7.1 Contamination Flashover Mechanism: When the layer of contaminants on an insulator is moistened by fog, dew, light rain, or snow, it will become more conductive and the leakage current along the surface of the insulator will greatly increase. Where the current density is the greatest (for suspension insulators near the pin and for post insulator at the points of least diameter), heat caused by the increased leakage current will evaporate the moisture causing the formation of a dry band. These bands usually have a higher resistance than the adjacent moistened area which means that they will support almost all the voltage across them. This will result in the breakdown of the air and the forming of an arc across the dry band. The arc will cause the moisture film at the dry band edges to dry out enlarging the dry band, eventually to the point where the band is just below the air breakdown value and if an increase in precipitation occurs causing a lowering of contaminant resistance, a second breakdown would occur. If conditions are right, a cycle of repeated and ever-increasing surges will be set up which will result in several discharges joining together, elongating and bridging the entire insulator and resulting in a power arc.

8.7.2 Effect of Insulator Orientation: The orientation of the insulators has an effect on contamination performance. Vertical strings of suspension insulators or vertical post insulators do not wash well in the rain because of the sheltering effects of the insulator skirts. Contaminants will tend to remain on the underside of the insulator which is not immune from the moistening effects of fog or wind blown rain and snow. Horizontally oriented suspension insulators and post insulators have their undersides more thoroughly washed by the rain and therefore tend to fare better than vertical insulators in contaminated areas. Of course, if it does not rain, the better washing does not make a difference. Another advantage of insulators in nonvertical positions is that any ionized gases caused by arcing will not be of any aid in setting up conditions where an arc could jump from one bell to another or along the skirts of a vertical post.

8.7.3 Designing for Adverse Contamination Conditions: There are several means available for improving line insulation performance in a contaminated atmosphere.

One way to compensate for contaminated conditions is to increase the leakage distance of the insulation. The leakage distance is the distance along the surface of the insulators from the top of the string (or post) to the energized hardware, not including any metal such as insulator caps and pins.

Table 8-4 gives recommended leakage distances for various levels of contamination. The increased leakage distance can be obtained by either adding additional standard insulator bells (using a longer post insulator)

or by using fog insulators which have more leakage distance for the same overall insulator length. The additional leakage distance on fog insulators is obtained by having more and/or deeper skirts on the underside of the insulator bell. The shape of the insulator, in addition to the leakage distance has an effect on contamination performance especially when fog units are being used. Therefore, experience with various types of fog units should be taken into account.

One very important factor that should be taken into account in considering contamination problems associated with insulation is previous successful insulation designs being used in the same area or in other areas where there are similar conditions.

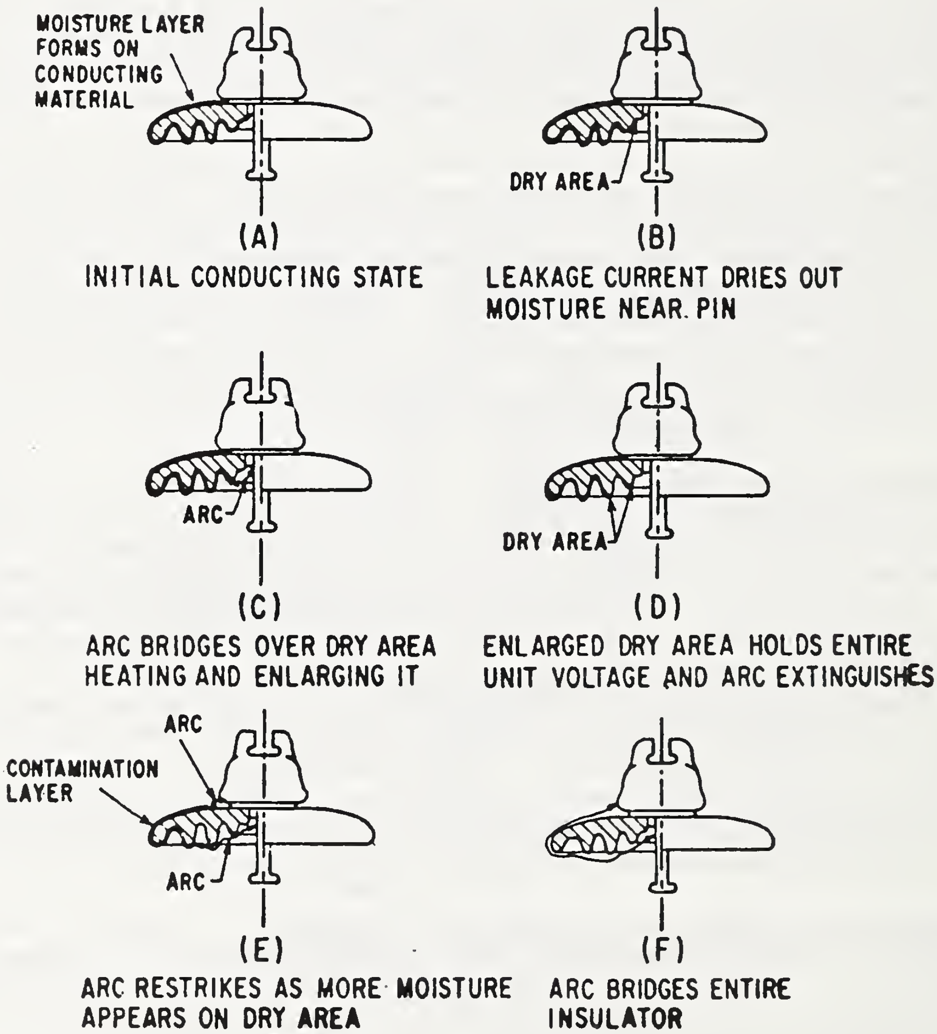


FIGURE 8-5: THE CONTAMINATION BREAKDOWN PROCESS OF A SINGLE INSULATOR UNIT.

TABLE 8-4

SUGGESTED LEAKAGE DISTANCES FOR CONTAMINATED AREAS

Pollution Level	Environment	Equivalent Amount NaCl mg/cm^2	Suggested Leakage Distance mm/kV rms L-G (in/kV)
Very Light	Areas without industries and with low density of houses equipped with heating plants; areas with some density of industries or houses but subsect to frequent winds and/or rainfall. All areas must be situated far from the sea or at a high altitude and must in any case not be exposed to winds from the sea.	0-0.03	NA-25 mm (NA-1.0 in.)
Light	Areas with industries not producing particularly polluting smoke and/or with average density of houses equipped with heating plants; areas with high density of houses and/or rainfall; areas exposed to winds from the sea but not too close to the coast.	0.03-0.06	25-32 mm (1.0-1.25 in.)
Moderate	Areas with high density of industries and suburbs of large cities with high density of heating plants producing pollution; areas close to the sea or in any case exposed to relatively strong winds from the sea.	0.06-0.1	38-44 mm (1.5-1.75 in.)
Heavy	Areas generally of moderate extent, subjected to industrial smoke producing particularly thick conductive deposits; areas generally of moderate extent, very strong and polluting winds from the sea.	0.1-.25	50-64 mm (2.0-2.5 in.)

An alternative to increasing the total leakage distance of the insulator string is to use a **resistance graded insulator**. These insulators have a glaze that permits a small but steady leakage current to flow over their surface. This leakage current gives the insulator much better contamination performance without having to increase leakage distance. The base of the resistance graded insulator should be solidly bonded to the structure ground wire to permit the leakage current to flow easily to the ground. In determining whether to use this type of insulator, its advantages and disadvantages as listed below must be weighed against one another.

ADVANTAGES	DISADVANTAGES
No extra leakage distance required.	Higher initial costs.
No washing, or at least much less washing of insulators required.	Small but continuous power loss.
No radio noise (due to more even voltage distribution across string).	They do not always prevent contamination flashovers in very heavily contaminated areas.

The **washing of the insulators** in order to remove the contaminants is a step that can help. This step should not be used in place of properly designing for contamination but rather should be used in addition to the other steps where it is felt necessary.

The performance of insulators in a contaminated environment can be improved by **coating the surface with a suitable silicone grease**. The grease absorbs the contamination and repels water. It is necessary, however, to remove and replace the grease at intervals determined by the degree of contamination. As with washing, the use of a grease should only be considered as a remedial step. Resistance graded insulators should not be greased.

8.8 <u>Mechanical Considerations</u>:

8.8.1 <u>Suspension Bell Insulators</u>: Under NESC loading district conditions, suspension bell insulators should not be loaded to more than 40 percent of their ANSI standard M&E rating. If a heavier loading than the NESC district loading can be expected to occur with reasonable regularity, then the 40 percent loading limit should be maintained at the higher loading limit. It should be noted that suspension insulators have a "test" value marked on them that is half of the M&E rating value. M&E strength is a value determined by a combined mechanical and electrical test where the insulator has a voltage impressed across it while a mechanical load is gradually applied to the insulator.

Under extreme ice or high wind (50-year mean recurrence interval wind conditions) the load on the insulator should not exceed 70 percent of the M&E strength of the insulator.

Generally, insulators with a 15,000 pound M&E rating will be satisfactory for tangent structures. However, stronger insulators may be needed on long spans with large conductors and at deadends and angles where the insulators carry the resultant conductor tension.

8.8.2 Vertical Post and Pin Insulators Mounted on Crossarms: The maximum transverse load, whether from standard NESC loading district loadings alone or from a combination of loading district loading and the resultant of conductor tension on line angles, should be limited to 2,224 N (500 lbs.) for standard single pin type REA structures, and 3,336N (750 lbs.) for standard vertical post type structures. It is possible that greater limiting values may be obtained through the use of special structural modifications. The limit will prevent excessive stress on the insulator, the tie wires (if used), insulator pin (if used), and the wood crossarm. The transverse load can be doubled by using double pin or post construction.

8.8.3 Horizontal Post Insulators: Under NESC loading district conditions, horizontal post insulators must not be loaded to more than 40 percent of their ultimate cantilever strength. As with suspension insulators, if a loading more severe than the NESC loading can be expected to occur with reasonable regularity, then the higher loading should be used. Under extreme ice conditions, the cantilever load on horizontal post insulators should not exceed 70 percent of the ultimate strength.

When a line angle is turned at a horizontal post structure, some or all of the insulators will be in tension. Under either standard NESC loading conditions or more severe conditions, if deemed warranted, the tension load on the insulator must not exceed 50 percent of the ultimate tension strength of the insulator. Under extreme loading conditions, the tension load must not exceed 80 percent of the tension strength of the insulator.

The above cantilever and tension loading limits apply simultaneously. The cantilever loading limit is not affected by the tension limit.

TABLE 8-5
SUMMARY OF RECOMMENDED INSULATOR LOADING LIMITS

Insulator Type	NESC Loading District Loading	Extreme Loading
Suspension	40%	70%
	(% of ANSI standard M&E strength)	
Horizontal Post		
Cantilever	40%	70%
Tension, Compression	50%	80%
	(% of appropriate rated ultimate strength value)	
Vertical Post	3,336 N (750 lbs.)	---
Vertical Pin Insulator (Mounted on the Crossarm)	2,224 (500 lbs.)	---

8.8.4 Coordination of Insulator Strength with Strength of Associated Hardware: Care should be taken to coordinate the strength of the hardware associated with the insulator with the strength of the insulator itself.

8.9 Special Considerations for Horizontal Post Insulators: There are two special considerations that must be mentioned in relation to horizontal post insulators.

8.9.1 Insulator Grounding: Where the structure ground wire passes near horizontal post insulators, it should be either stood off from the pole by means of a nonconducting strut or must be solidly bonded to the base of the insulator. This is necessary to avoid radio noise problems.

8.9.2 Mechanical Overload Problems: Post insulators mounted on steel, concrete, or in some cases, on wood structures using H-class poles, have in the past experienced cascading mechanical failures due to impact loads because of the relative rigidity of the structures. In order to avoid such occurrences, it is recommended that on rigid structures, the post insulators be equipped with deformable bases, shear pin devices, or other such means of relieving mechanical overloads.

8.10 Example 8-1, Additional Insulation for High Altitudes: A 161 kV line is to be built in an area whose altitude ranges from 1655 m (5430 ft) to 2310 m (7580 ft). Determine how much additional insulation, if any, is necessary.

8.10.1 Solution: The elevation change for the line from its lowest point to its highest point is less than 1500 m (5000 ft), and therefore the insulation should be based on the weighted average altitude. Since we do not know the distribution of the line at the various altitudes, we will have to assume a uniform distribution. Thus:

$$\text{average altitude} = \frac{1655 + 2310}{2} = 1982.5 \text{ m}$$

$$\text{average altitude} = \frac{5430 + 7580}{2} = 6505 \text{ ft.}$$

From Figure 8-3 the derating factor for an average altitude of 1982.5 m (6505 ft) is .81 and since section 8.5 indicates that additional insulation is needed if the derating factor is less than .90, additional insulation will be needed here.

Let us try one additional bell at this voltage. One additional bell means a total of 11. From Appendix C, the low frequency dry flashover of 11 bells is 640 kV. Taking into account the derating factor, the low frequency dry flashover value of this string is:

$$(.81)(640 \text{ kV}) = 518 \text{ kV}$$

According to the text, the insulation value should be brought up to approximately 90 percent of the sea level value which for 161 kV is:

$$(.9)(590) \text{ kV}) = 531 \text{ kV}$$

(590 kV is the low frequency dry flashover value of 10 bells at sea level).

Therefore, the addition of one extra bell will not quite bring the insulation level up to the 90 percent of sea level value which would seem to indicate the necessity of adding two extra bells. Some judgment should be exercised as to whether the second additional bell is used. Even though only one bell extra does not quite provide enough additional insulation, it is close and if the expected frequency and severity of lighting storms is not particularly high, it will probably be sufficient.

The final answer is that at least one and possibly two extra bells are necessary depending upon experience and judgment.

8.11 Example 8-2, Maximum Vertical Span Due to Horizontal Post Insulator Strength: A 115 kV line is to be built using horizontal post insulators with a cantilever strength of 12,460 Newtons (2,800 pounds). The conductor to be used is 795 kcmil 26/7 ACSR. Determine the maximum vertical span under a) heavy loading district conditions and b) under an extreme ice load, no wind, and 38 mm (1.5 in.) of radial ice (see Chapter 11 for definitions of heavy loading and Chapter 9 for information on conductors).

8.11.1 Solution: From Appendix B. Conductors, the weights per unit length for the two conditions of the conductor are:

Heavy loading:	
12.7 mm (1/2 in)	38 mm (1.5 in)
Radial ice:	
30.557 N/m 2.0938 lbs/ft.	86.962 N/m 5.9588 lbs/ft.

(Metric value converted from English value listed in table).

a. Span Limits for Heavy Loading District:

$$\frac{12460\ \text{N}(.40)}{30.555\ \text{N/m}} = 163.1\ \text{m}$$

$$\frac{2800\ \text{lbs}(.40)}{2.0938\ \text{lbs/ft}} = 534.9\ \text{ft.}$$

b. Span Limits for Extreme Ice Condition:

$$\frac{12460\ \text{N.}(.70)}{86.958\ \text{N/m}} = 100\ \text{m}$$

$$\frac{2800\ \text{lbs}(.70)}{5.9588\ \text{lbs./ft.}} = 329\ \text{ft.}$$

c. The maximum vertical span is therefore 100 m (329 ft.)

8.12 Example 8-3, Insulator M&E Ratings: A conductor has a maximum tension under heavy loading district conditions of 46,124 N (10,200 lbs). Under extreme radial ice of 38 mm (1.5 in), it has a maximum tension of 77,728 N (17,474 lbs.). Determine the minimum M&E rating of suspension bell insulators to be used in tension strings (those insulator strings that are in line with the conductor and bear its full tension).

8.12.1 Solution:

a. Under NESC loading district conditions, the insulator can be loaded up to 40 percent of its M&E rating. Therefore:

$$(\text{M\&E rating})(.4) = \text{load}$$

$$\text{M\&E rating} = \frac{\text{load}}{.4}$$

$$\text{M\&E rating} = \frac{46121 \text{ N}}{.4} = 115{,}300 \text{ N}$$

$$\text{M\&E rating} = \frac{10200 \text{ lbs.}}{.4} = 25500 \text{ lbs.}$$

b. Under extreme ice conditions the insulator can be loaded to 70 percent of its M&E rating. Therefore:

$$(\text{M\&E rating})(.7) = \text{load}$$

$$\text{M\&E rating} - \frac{\text{load}}{.7}$$

$$\text{M\&E rating} = \frac{77724 \text{ N}}{.7} = 11103 \text{ N}$$

$$\text{M\&E rating} = \frac{17474 \text{ lbs.}}{.7} = 24963 \text{ lbs.}$$

c. Based on ANSI standard M&E ratings, the insulators to be used should have a minimum standard rating of 111,200 N (25,000 lbs).

9. CONDUCTORS AND OVERHEAD GROUND WIRES

9.1 Introduction: Of all the components that go into making up a transmission system, nothing is more important than the conductors. There are a surprising number of variables and factors that must be considered when dealing with conductors. Some of these are:

a. Conductor type
b. Conductor size
c. Economic considerations
d. Conductor thermal capacity
e. Conductor tensions
f. Corrosive atmosphere considerations
g. Radio noise
h. Conductor motion considerations

9.2 Types of Conductors: There are several types of conductors currently available, some of which are used much more extensively than others. Given below is a list and description of many of the conductor types.

9.2.1 ACSR (Aluminum Conductor Steel-Reinforced) 6/1, 26/7, and 54/7 Strandings: This is the most common type of conductor used today. It is a concentrically stranded conductor composed of one of more layers of hard-drawn 1350 aluminum wire stranded with a high-strength galvanized steel core. The core may be a single wire or stranded depending on the size. Because of the numerous stranding combinations of aluminum and steel wires that may be used, it is possible to vary the proportions of aluminum and steel so as to obtain a wide range of current carrying capacities and mechanical strength characteristics.

The steel core may be furnished with three different coating weights of zinc. The standard weight zinc coating is the "A" coating. To provide better protection where corrosive conditions are present, a class "B" or "C" zinc

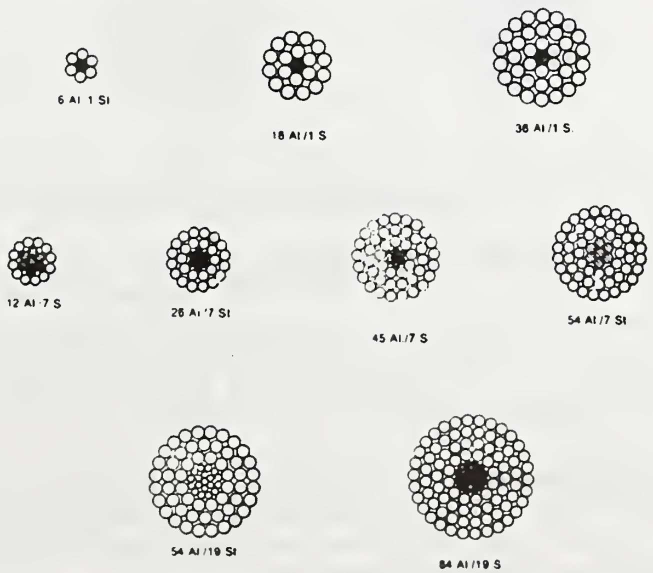


FIGURE 9-1: TYPICAL ACSR STRANDINGS

coating may be specified where "C" is the heaviest. Also available is an aluminum coating, aluminized, (not to be confused with an aluminum cladding which is thicker). There is a slight reduction in the conductor rated strengths when the heavier zinc and aluminized coating are used.

9.2.2 ACSR/AW (Aluminum Conductor, Aluminum-Clad Steel Reinforced): This type of conductor is similar to conventional ACSR except the core wires are high strength aluminum-clad steel instead of galvanized steel. Aluminum-clad core wire has a minimum aluminum thickness of 20 percent of its nominal wire radius. This cladding provides a greater protection against corrosion than any of the other types of steel core wire, thus making it applicable for use in areas where corrosive conditions are severe. Its tensile strength and stress at 1 percent extension are somewhat less than that for Class "A" galvanized coated steel core wire. However, it has a significantly lower resistivity than galvanized steel core wire which may result in somewhat lower losses.

9.2.3 1350 Aluminum Conductors: This conductor is made up entirely of hard-drawn 1350 aluminum strands. 1350 aluminum is essentially a pure aluminum (minimum aluminum content 99.5%). It is usually less expensive than other conductors, but it is not as strong and tends to sag more. It is most useful where electrical loads are heavy and where spans are short and mechanical loads are low.

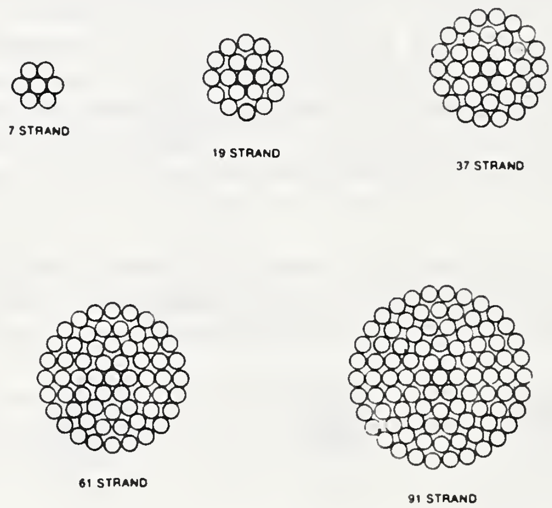


FIGURE 9-2: 1350 ALUMINUM CONDUCTOR STRANDINGS

9.2.4 AAAC-6201 (All Aluminum Alloy Conductor - 6201 Alloy): This type of conductor is composed entirely of 6201-T81 high strength aluminum alloy wires, concentrically stranded and similar in construction and appearance to 1350 aluminum conductors. It strength is comparable with that of ACSR. It was developed to fill the need for a conductor with higher strength than that obtainable with 1350 aluminum conductors, but without a steel core.

The conductors were designed to have diameters the same as those of standard sizes and strandings of ACSR. The DC resistance of the 6201 conductors and of the standard ACSR's of the same diameters are approximately the same. This conductor may be used where contamination and corrosion of the steel wires is

a problem. It has proven to be somewhat more susceptible to vibration problems than standard ACSR conductors strung at the same tension. The use of conductor sizes smaller than 3/0 ACSR equivalent on suspension type constructions should be avoided because the light weight of the conductor may result in inadequate downward force on the suspension insulators causing radio noise and insulator swing problems.

9.2.5 ACAR Aluminum Conductor Alloy Reinforced): This type of conductor consists of 1350 aluminum strands reinforced by a core and/or otherwise distributed wires of higher strength 6201 alloy. Because the 6201 reinforcement wires in ACAR may be used in varying amounts, almost any desired property of strength-conductivity between conductors using all 1350 wires and those using all 6201 wires may be achieved. Strength and conductivity characteristics of ACAR are somewhat between those of a 1350 aluminum conductor and a 6201 conductor.

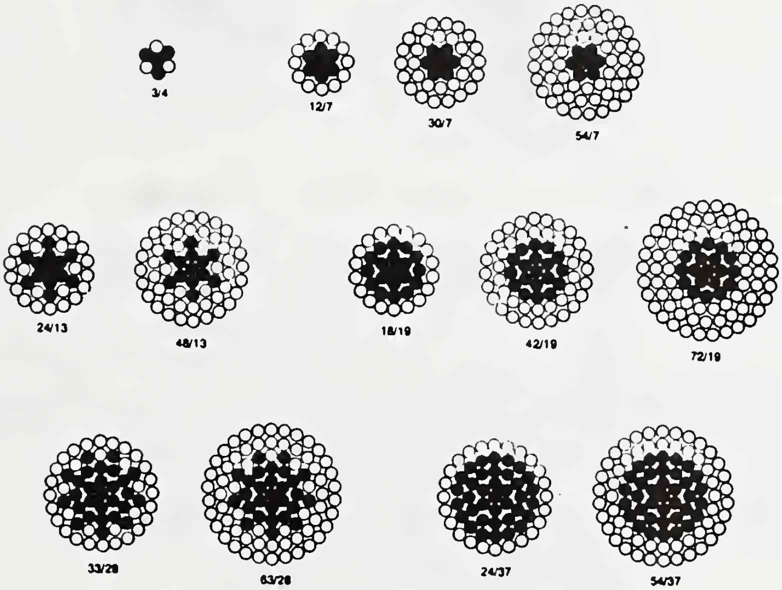


FIGURE 9-3: ACAR STRANDINGS

9.2.6 AWAC (Aluminum-Clad Steel Conductor): This conductor is made up of aluminum-clad steel and 1350 aluminum strands. This conductor includes the aluminum content of the aluminum-clad strands in the total aluminum cross-sectional area. For the same designated size and stranding, the AWAC conductors have a slightly smaller diameter than standard ACSR. For smaller AWAC sizes, the ratio of aluminum-clad to aluminum strands is varied to provided a wide range of rated strengths.

9.2.7 ACSR/SD (Aluminum Conductor Steel Reinforced - Self Damping): This type of special conductor has been in moderately widespread use for several years. It is a concentrically stranded conductor composed of two layers of trapezoidal-shaped wires or two layers of trapezoidal-shaped wires and one layer of round wires of hard-drawn 1350 aluminum stranded with a steel core. The core may be a single wire or stranded depending on the size.

From a performance point of view, the conductor is the same as conventional ACSR except that it is self damping; that is, the conductor is designed to limit aeolian vibration to a safe level. The damping occurs because of the interaction between the two trapezoidal layers and between the trapezoidal layers and the core. To date, experience with this type of conductor has been generally good. It does appear to do a satisfactory job of damping out aeolian vibration. Some special considerations associated with this conductor are that (1) during stringing, special precautions must be taken and procedures followed to avoid difficulties, and (2) it is more expensive per pound than conventional ACSR, but its ability to be strung at higher tensions may result in economic advantages that outweigh its extra cost.

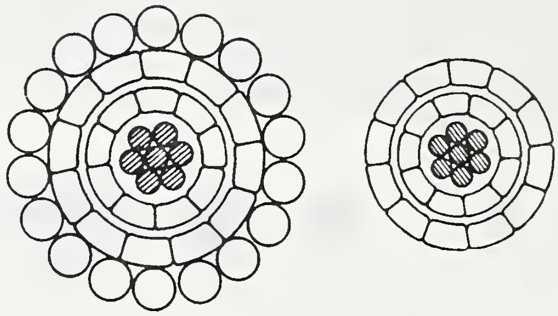


FIGURE 9-4: TYPICAL ACSR/SD STRANDING

9.2.8 <u>ACSR/TW, Shaped Strand Concentric - Lay Stranded Aluminum Conductors, Steel Reinforced</u>: As with ACSR/SD, the conductor layers are trapezoidal-shaped aluminum wires. However, unlike ACSR/SD conductor, no gaps exist between layers of the strands. The compact trapezoidal-shaped wires result in an increased capacity for an equivalent standard range of ACSR conductor diameters. Conversely, for a given aluminum area, a smaller conductor diameter than the round wire ACSR equivalent can be designed which will reduce the wind on wire load in the structure. The above are important advantages when existing transmission lines are considered for uprating or reconductoring. Other advantages and improvements of ACSR/TW include corrosion resistance and lower temperature gradient.

The use of ACSR/TW should be based on an economic evaluation to determine whether savings will be achieved in comparison with the use of conventional ACSR conductor.

9.2.9 <u>AACSR (Aluminum Alloy Conductor, Steel Reinforced)</u>: This type of conductor is the same as a conventional ACSR conductor except that the 1350 strands have been replaced with higher strength 6201 alloy strands. The resulting greater strength of the conductor allows the sags to be decreased without exceeding the standard conductor percent tension limits. This type of conductor is primarily used at river crossings where sag limitations are important. The higher tensions associated with this type of conductor require that special attention be paid to the possibility of aeolian vibration.

9.2.10 <u>SSAC, Steel Supported Aluminum Conductor</u>: In appearance, this conductor is the same as ACSR. The only difference is that the aluminum strands are fully annealed. This means that the conductor depends mostly on the steel for its strength and that its sag characteristics are essentially

those of steel. This contrasts with ACSR where there is strength contribution from the aluminum. This conductor has found its greatest application in reconductoring of existing lines.

9.3 Selecting a Conductor Type:

9.3.1 REA Standards: The conductor selected should generally be of a type and stranding listed as being acceptable for use on REA systems. See the REA Bulletin 1728C-100, List of Materials Acceptable for Use on Systems of REA Electrification Borrowers.

9.3.2 Corrosion Considerations: Standard ACSR conductor should not be used in areas of severe corrosion. Rather, a conductor without a steel core wire or one with aluminum-clad core wire should be used. An ACSR conductor with an aluminum coated or a heavier weight zinc coated steel core wire may be considered if experience with such material has been successful.

9.3.3 Economics: The relative cost of one conductor type versus another is very important. When comparing costs, one should take into consideration overall line costs. A less expensive conductor with greater sags requiring shorter spans or higher structures compared to a more expensive conductor with lesser sag, may not be the most economical selection when overall line costs are considered.

9.3.4 Strength: The strength of the conductor and its ability to sustain the mechanical loads without unreasonable sags must be evaluated.

9.4 Selection of Conductor Size

9.4.1 Minimum Conductor Size: The table below gives the minimum allowable conductor sizes for each of the standard REA transmission voltages. The minimums are based on a combination of radio noise, corona, and mechanical sag and strength considerations. If a conductor type other than ACSR or 6201 AAAC is used, the conductor diameter should not be less than the diameter of the ACSR specified for the particular voltage concerned.

TABLE 9-1

RECOMMENDED MINIMUM CONDUCTOR SIZES

kV_{LL}	ACSR	AAAC - 6201
34.5	1/0	123.3 kcmil
46	2/0	155.4 kcmil
69	3/0	195.7 kcmil
115	266.8 kcmil	312.8 kcmil
138	336.4 kcmil	394.5 kcmil
161	397.5 kcmil	465.4 kcmil
230	795 kcmil	927.2 kcmil

9.4.2 Voltage Drop Considerations: Not only should the conductor be sufficiently large to meet the requirements of Section 1 above, but it should also meet the system voltage drop requirements. Typically the conductor would have to have sufficiently low impedance so that under a given set of electrical loading conditions, the voltage drop would not exceed approximately

5 percent. In general, it is the longer lines where voltage drop becomes a factor. Voltage drop can be evaluated by either running a load flow computer program or by using the estimating tables in REA Bulletin 1724E-201, Electrical Characteristics of REA Alternating Current Transmission Line Designs.

9.4.3 Thermal Capability Considerations: When sizing a phase conductor, the thermal capability of the conductor (ampacity) should also be considered. The conductor should be able to carry the maximum expected long-term load current without overheating. Generally, a conductor is assumed to be able to heat up to 75°C (167°F) without any long-term decrease in strength. Above that temperature, there may be a decrease in strength depending on how long the conductor remains at the elevated temperature. A conductor's ampacity depends not only upon its assumed maximum temperature, but also on the wind and sun conditions that are assumed. See Appendix B for ampacity tables.

9.4.4 Economic Considerations: Economics is an important factor in determining conductor size. Rarely would the minimum conductor sizes given in Table 9-1 be the most economical in the long run. The additional cost of a larger conductor may be more than offset by the present worth of the savings resulting from the lower losses during the entire life of the conductor. A proper economic analysis should consider the following factors for each of the conductor sizes considered:

a. The total per kilometer (mile) cost of building the line with the particular conductor being considered.

b. The present worth of the energy losses associated with the conductor.

c. The capital cost per kilowatt of loss of the generation substation and transmission facilities necessary to supply the line losses.

d. Load growth.

The results of an economic conductor analysis can often be best presented and understood when presented in a graphical form as shown in Figure 9-5. At an initial load of approximately 200 MW, 1272 kcmil becomes more economical than 795 kcmil. 954 kcmil is not economical at any load level included on the graph.

9.4.5 Standardization and Stocking Considerations: In addition to the above factors, the problem of standardization and stocking must be considered. A proliferation of conductor sizes in use on a power system is undesirable because of the expense of stocking many sizes. When a conductor is electrically and economically optimum, but is not a standard size already in use on the system, the additional cost and complications of having one more conductor size to stock should be weighed against the advantages of using an optimum conductor.

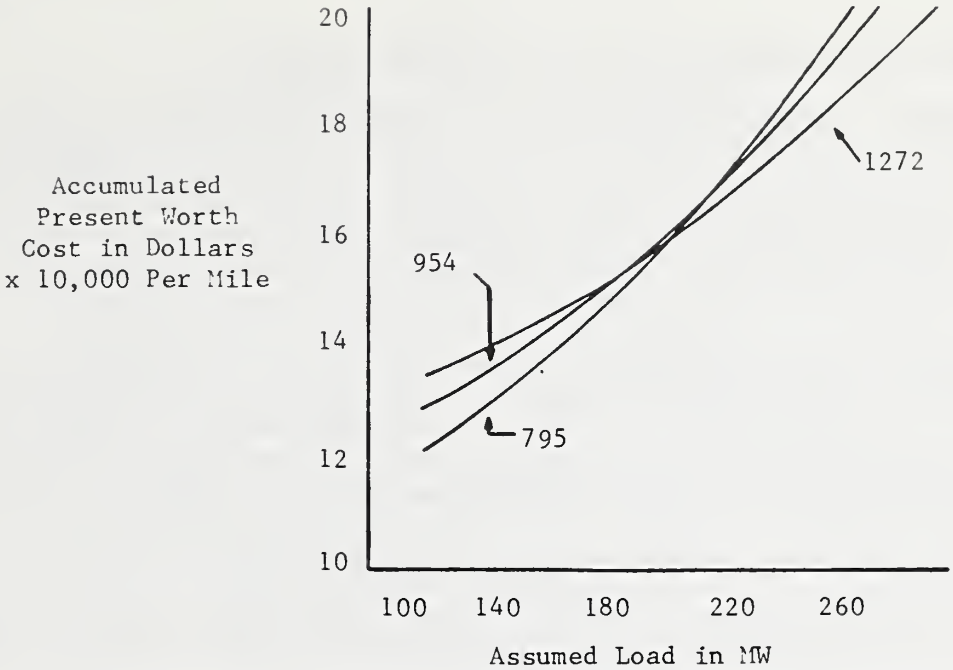


FIGURE 9-5: RESULTS OF A TYPICAL ECONOMICAL CONDUCTOR ANALYSIS - 230 kV, 795 vs 954 vs 1272 kcmil ACSR

9.5 Overhead Ground Wires (OHGW)

9.5.1 High Strength or Extra High Strength Galvanized Steel Wires: For high strength wires the allowable sizes are 3/8" and 7/16", while for extra high strength wires, the allowable sizes are 5/16", 3/8", and 7/16". Note that 1/4" strand is not acceptable for use as overhead ground wires as is also Siemens Martin grade wires of all sizes. Overhead ground wires do not have brazed or welded joints in accordance with ASTM Specification A-363. Steel wires are available in three weights of zinc coating. The standard weight is designated as A and the greater weights are designated B and C.

9.5.2 Aluminum-Clad Steel Strand: Instead of a thin coating of zinc, this material has a thick cladding of aluminum which makes it more resistant to corrosion and gives it greater conductivity.

The sizes of this material that may be used as overhead ground wires are 7 No. 10AWG, 7 No. 9AWG, 7 No. 8AWG, and 7 No. 7AWG. The material is in accordance with ASTM Specification B416.

9.5.3 Selecting a Size and Type: Selecting an overhead ground wire size and type is dependent upon only a few factors, the most important of which is how the sag of the OHGW coordinates with that of the phase conductors. Other factors that may have to be considered are corrosion resistance and conductivity.

If a line is to be located in a seacoast region or in another location where there is a highly corrosive atmosphere, aluminum-clad steel wire should be considered. If the OHGW is to be used to carry any type of communication signal, or if large magnitudes of lightning stroke currents are expected, a higher conductivity than normal may be desirable.

9.6 Conductor and Overhead Ground Wire Design Tensions:

9.6.1 General: Throughout the life of a transmission line, the conductor tensions may vary between 10 and 60 percent or more of rated conductor strength due to change in loading and temperature. Most of the time, however, the tension will vary within relatively narrow limits, inasmuch as ice, high winds, and extreme temperatures are relatively infrequent in many areas. Such normal tensions may actually be more important in determining the life of the conductor than higher tensions which are experienced infrequently.

9.6.2 Conductor Design Tensions: In Table 9-2 are REA recommended maximum conductor tension values for ACSR and 6201 AAAC conductors that should be observed for the ruling span. It should be stressed that the values given are maximum design values. If deemed prudent, tensions less than those specified or loadings greater than the standard loading condition (tension limit "B3" of the table) may be used. However, unless the occurrences of loadings in excess of the NESC loading are frequent, it is unwise to base the selection of a "maximum loading" condition on a single or very infrequent case of excessive loading. Mountainous areas above 1200 meters (4000) feet) in which ice is expected should be considered to be in heavy loading district even if they are not.

In open areas where steady winds are encountered, aeolian vibration can be a problem especially if conductor tensions are high. Generally, lower tensions at conditions at which aeolian vibration is likely to occur, can reduce vibration problems (see section 9.1 for further discussion).

Explained below are the several conditions at which maximum conductor tension limits are specified.

a. Initial Unloaded Tension: The initial unloaded tension refers to the state of the conductor when it is initially strung and is under no ice or wind load.

b. Final Unloaded Tension: After a conductor has been subject to the assumed ice and wind loads, and/or long time creep, it receives a permanent or inelastic stretch. The tension of the conductor in this state, when it is again unloaded, is called the final unloaded tension.

c. Standard Loaded Tension: The loaded tension refers to the state of a conductor when it is loaded to the assumed simultaneous ice and wind loading for the National Electrical Safety code (NESC) loading district concerned (see Table 11-1, for the loads associated with each loading districts). To the vector resultant of the transverse and vertical loads, the following constants are to be added to get total load on the conductor:

	Heavy	Medium	Light
N/m	4.4	2.9	.73
(lbs/ft)	.30	.20	.05

TABLE 9-2

RECOMMENDED REA CONDUCTOR AND OVERHEAD
GROUND WIRE TENSION AND TEMPERATURE LIMITS*

A. Temperatures

1. Tension limits 1, 2 and 3 below are to be met at the following temperatures:

Heavy loading district	-17.8°C (0°F)
Medium loading district	-9.4°C (15°F)
Light loading district	-1.1°C (30°F)

2. Limit 4 are to be met at the temperature at which the extreme wind is expected.

3. Limit 5 are to be met at 0°C (32°F).

B. Tension Limits in Percent of Conductor Rated Strength.

Tension Condition (See text for explanation)	Phase Conductor	OHGW High Strength Steel	OHGW Extra High Strength Steel
1. Max. initial unloaded	33.3**	25	20
2. Max. final unloaded	25***	25	20
3. Standard loaded (usually NESC district loading)	50	50	50
4. Max. extreme wind (A)	70****	80	80
5. Max. extreme ice (A)	70****	80	80

Note:
(A) These limits are for tension only. When conductor stringing sags are to be determined, limits 1, 2 and 3 should be considered as long as tensions at conditions 4 and 5 are satisfactory.

*Tension limits do not apply for self-damping and other special conductors.

**In areas prone to aeolian vibration, a value of approximately 20 percent at the average annual minimum temperature is recommended, if vibration dampers or other means of controlling vibration are not used (see section 9.9, page 9-19, for further details).

***For 62-1 AAAC, a value of 20 percent is recommended.

****For ACSR only. 6201 Aluminum use 60 percent.

The initial and final sags and tensions for "standard loaded" condition will be the same unless creep is the governing factor, in cases where the "standard loaded" condition is the maximum mechanical load used in the calculations. If another condition, such as extreme ice, is the maximum mechanical load, then the initial and final sags and tensions for the "standard loaded" condition can be significantly different from one another. In this case, it is important that the loaded tension limits be set for initial conditions.

d. Extreme Wind Tension: The extreme wind tension refers to the state of the conductor when it has a wind blowing on it of a value not less than the 50-year mean recurrence interval wind (see Appendix E). No ice should be assumed to be on the conductor.

e. Extreme Ice Tension: The tension in a conductor when it is loaded with an extreme amount of ice for the area concerned is called the extreme ice tension. It should be assumed that there is no wind blowing when the ice is on the conductor. Values of 25 to 50 mm (1 to 2 in.) of radial ice are commonly used as extreme ice loads.

9.6.3 Controlling Conditions: For a given ruling span, usually only one of the tension limit conditions will control the design of the line and the others will have relatively little significance insofar as line tensions are concerned.

If the conductor loading under extreme ice or wind loads is greater than under the "standard loaded" condition, calculated sag and tension values at other conditions could be somewhat different from what they would be if the "standard loaded" condition were the maximum case. In these situations stringing sags should be based upon limits 1, 2, and 3 only, as tensions at conditions 4 and 5 are satisfactory.

9.6.4 Overhead Ground Wire (OHGW): To avoid unnecessarily high mechanical stresses in the OHGW, supporting structures, and guys, the OHGW should not be strung with any more tension than is necessary to coordinate its sags at different conditions with the phase conductors. See Chapters 6 and 8.

9.7 Ruling Span:

9.7.1 Why a Ruling Span? If all spans in a section of line between deadends are of the same length, uniform ice and wind loads will result in equal conductor tension in all spans. But, span lengths usually vary in any section of line, with the result that temperature change and ice and wind loads will cause conductor tensions to become greater in the longer spans and less in the shorter spans when compared to the tensions of loaded uniform spans. The movement of the insulator strings and/or the flexing of the structures will tend to reduce this unequal tension. It is possible, however, for conductor tension in long spans to reach a value greater than desired unless the line is spotted and the conductor strung to limit this undesirable condition.

A ruling span is an assumed uniform design span which approximately portrays the mechanical performance of a section of line between its deadend supports. The use of a ruling span in the design of a line assumes that flexing of the structure and/or insulator string deflection can occur at the intermediate

supporting structures so as to allow for the equalization of tension in the conductor between adjacent spans to the ruling span tension. The purpose of a ruling span in the design and construction of a line is to provide a uniform span length which is representative of the various lengths of spans between deadends so that sags and clearances can be calculated for structure spotting and conductor stringing.

9.7.2 Calculations of the Ruling Span: On a line where all spans are equal, the ruling span is the same length as the line spans. Where spans vary in length, the ruling span is between the shortest and the longest span lengths on the line, but is mainly determined by the longer spans.

a. Approximate Method. Some judgment must be exercised in using this method as a large difference between the average and maximum span may cause a substantial error in the ruling span value.

$$RS = L_{avg} + 2/3(L_{max} - L_{avg}) \qquad \text{Eq. 9-1}$$

where:

RS = ruling span in meters (feet).
L_{avg} = average span in meters (feet).
L_{max} = maximum span in meters (feet).

b. Exact Method. The following is the exact formula for determining the ruling span:

$$RS = \sqrt{\frac{L_1^3+L_2^3+L_3^3+\ldots+Ln^3}{L_1+L_2+L_3+\ldots+L_n}} \qquad \text{Eq. 9-2}$$

where:

L_1, L_2, L_3, etc. = the different span length in the line in meters (feet).
Other symbols as previously defined.

9.7.3 Establishing a Ruling Span: As can be seen from Equation 9-2, the exact value of the ruling span can only be calculated after the structures have been spotted and all the span lengths determined. However, the ruling span has to be known in advance of structure spotting. Thus the ruling span must at first be estimated.

When following any procedure for estimating ruling span, it should be borne in mind that the estimation of a ruling span is as much of an intuitive process based on experience, judgment, and trial and error as it is a quantitative procedure. A good starting point for estimating ruling span is the height of the base structure. The base structure is the structure that is expected to occur most often throughout the line. After assuming a base structure height, subtract the minimum ground clearance value from the height of the lowest phase conductor above ground, at the structure. The allowable sag as limited by ground clearance is the result. Using this sag value and tables of sags for various ruling span lengths, a ruling span length can be chosen whose sag is approximately equal to the allowable sag for the base structure height. Or in other words, a ruling span is chosen to be approximately equal to the level

ground span -- the maximum span limited by line-to-ground conductor clearance for a particular height structure. If the terrain is flat or rolling, the above approximation should be followed. However, if it is rough, the ruling span should be somewhat greater than the level ground span.

The ruling span value initially chosen should be checked to see that it coordinates reasonably well with the minimum span values as limited by such factors as structure strength, conductor separation, galloping, etc. Also, Equation 9-1 should be used in conjunction with estimated maximum and average span values to further check the reasonableness of the estimated ruling span. If the initial estimate does not check out, the value should be changed and the procedure repeated.

If possible, the ruling span should be used throughout the length of the line, as deadending for the purpose of changing ruling spans is costly. In cases where the spans in one extended section of line are consistently and considerably longer or shorter than in another section of line, more than one ruling span may be unavoidable. It is a common practice to permit long spans to double the average span without deadends, provided conductor tension limits are satisfactory. In addition, short spans should not be less than approximately one-half of the ruling span. After the plan and profile sheets are plotted, the validity of the estimated ruling span value should be checked by comparing it to the actual value obtained. It is not essential that the estimated ruling span value be equal to the actual value, provided the estimated ruling span results in satisfactory ground clearance and economical structure spotting without excessive conductor tensions. However, if the difference between the estimated and actual ruling span is more than approximately 15 percent, the effects resulting from the difference should be carefully checked.

9.7.4 Effects of the "Wrong" Ruling Span: It is important that the actual ruling span be reasonably close to the ruling span value that is used to spot the line. If this is not the case, there may be significant differences between the predicted conductor tensions and clearances, and the actual values. There have been instances where sags greater than predicted resulting from an improper assumed ruling span have caused clearance problems. The table below will be of use in determining how conductor sags differ from the predicted value when there are differences between actual and assumed ruling span. The tension variation is opposite of that of the sags. Thus, increased sags mean decreased tension and vice versa.

TABLE 9-3

DIRECTION OF DEVIATION OF SAGS FROM
PREDICTED VALUES WHEN ACTUAL AND ASSUMED (DESIGN)
RULING SPAN VALUES ARE SIGNIFICANTLY DIFFERENT
(Applies to Unloaded Condition)

	Assumed RS > Actual RS	Assumed RS < Actual RS
Conductor temperature is less than temperature at which conductor was strung.	Actual Sag < Predicted INCREASED TENSIONS	Actual Sag > Predicted CLEARANCE PROBLEMS
Conductor temperature is greater than temperature at which conductor was strung.	Actual Sag > Predicted CLEARANCE PROBLEMS	Actual Sag < Predicted INCREASED TENSIONS

CLEARANCE PROBLEMS - Conductor sags greater than indicated on the plan and profile sheets may result in clearance problems.

INCREASED TENSIONS - Conductor tensions greater than anticipated will result.

9.8 <u>Determining Conductor Sags and Tensions</u>: The determination of conductor sags and tensions given a set of tension limits as outlined in Section 9.6 is a complex and difficult task. This is true because only one of the tension limits may control, and it is not always predictable which limit it will be. In addition, one must work with conductor stress strain curves which for a compound conductor such as ACSR can be rather complex.

The best method of obtaining conductor sag and tension values is to use one of the numerous computer programs written for that purpose. In using a computer program, several factors should be watched:

- The program should be written so that a check is made of all the limiting conditions simultaneously and the governing condition noted.
- The program should take into account conductor creep.
- The tension values given should be average tension values and not tension at support or horizontal tension values.
- The source of the stress strain data used should be indicated.

If computerized sag tension values are not available either from one's own program or from a manufacturer's, values can be generated using the graphical method given in the publication, "Graphic Method for Sag Tension Calculations for ACSR and Other Conductors," Publication No. 8, Aluminum Company of America, 1961.

9.9 Aeolian Vibration

9.9.1 General: Overhead conductors of transmission lines are subject to two different types of vibration: aeolian and galloping, both of which are produced by wind. The first type, aeolian vibration, is a high-frequency low-amplitude oscillation generated by a low velocity comparatively steady wind blowing across the conductors. This steady wind will create air vortices or eddies on the lee side of the conductor which will detach at regular intervals from the top and bottom area of the conductor creating a force on the conductor that is alternately impressed from above and below. If the frequency of the forces approximately corresponds to a frequency of a mode of resonant vibration of the span, the conductor will tend to vibrate in many loops in a vertical plane. The frequency of vibration depends mainly on conductor size and wind velocity and is generally between 5 and 100 Hz for wind speeds within the range of 0 to 24 kilometers per hour (15 miles per hour). The peak-to-peak amplitudes of vibration will cause alternating bending stresses great enough to produce fatigue failure in the strands of the conductor or OHGW at the points of attachment. Highly tensioned conductors in long spans are particularly subject to vibration fatigue. This vibration is generally more severe in flat open terrain where steady winds are more often encountered.

The frequency and loop length of the vibration can be determined using the following formulae.

Frequency of the vibration:

$$f = 51.5 \frac{V}{d_c} \qquad \text{(Metric) Eq. 9-3}$$

$$f = 3.26 \frac{V}{d_c} \qquad \text{(English) Eq. 9-4}$$

where:

f = frequency of conductor vibration in Hertz.
V = transverse wind velocity in kilometers per hour (miles per hour)
d_c = conductor diameter in millimeters (inches).

Loop Length (for a conductor that is assumed to have negligible stiffness):

$$LL = \frac{1}{2f}\sqrt{\left(\frac{(T_{avg})(g)}{w_c}\right)} \qquad \text{Eq. 9-5}$$

where:

LL = loop length in meters (feet).
T_{avg} = average conductor tension in Newtons (pounds).
w_c = weight of conductor in Newtons per meter (pounds per foot)(For standard gravity 1 kg = 9.81 N).
g = 9.81 m/sec^2 (32.2 ft/sec^2).
Other symbols as previously defined.

9.9.2 Designing for Vibration Problems: If an area is expected to have aeolian vibration problems, there are several measures given below that may be taken in order to mitigate possible problems. The measures are not necessarily mutually exclusive; more than one measure may be used simultaneously.

a. Reduced Tension: The two line design variables that have the greatest effect upon a line's vibration characteristics are conductor tension and span length. Singly or in combination, these two variables can be reduced to the point where the level of vibration, without any vibration damping devices, will not be damaging. For similar sag characteristics, conductors of different types, with their different characteristics, may require a different degree of vibration protection.

A rule of thumb that has proved generally successful in eliminating vibration problems is to keep the conductor tension for short and medium length spans under initial unloaded conditions at the average annual minimum temperature to approximately 20 percent or less of the conductor's rated strength. For long spans, a somewhat lower percent tension limit should be used. Due to their vibration characteristics, 6201 AAAC and 1350 aluminum conductors should be held to tensions somewhat lower than the 20 percent value, even for relatively short spans.

b. Armor Rods: Armor rods, in addition to reinforcing the conductor at the support points, do provide a small amount of damping of aeolian vibration. In lines with lower conductor tension and shorter spans, this damping may provide adequate protection against conductor strand fatigue.

c. Cushioned Suspensions: Cushioned suspensions combine armor rods with a resilient cushioning of the conductor. They do provide somewhat more damping than armor rods, but the degree of damping is still relatively small compared to vibration dampers.

d. Dampers: Stockbridge and other types of dampers are effective devices for controlling vibration. The selection of damper sizes and the best placement of them in the spans should be determined by the damper or conductor manufacturer on the basis of the tension, weight, and diameter of the conductor and the expected range of wind velocities. The length of the suspension clamp and the effect of the armor rods or cushioned suspensions should also be considered. With new efficient damper designs and usual conductor tensions and span lengths, one damper is installed near one span support joint. For long spans, additional dampers may be required.

9.10 Galloping: See Chapter 6 for details.

9.11 Maximum Possible Single Span: For a given span length, as the sag is increased, the tension at the support will decrease until a point is reached where the tension will begin to increase due to the weight of the conductor. This point occurs when the sag is equal to .337 times the span length. The relationship between span length and tension can be expressed as:

$$L_{max} = 1.33 \frac{T}{w_c} \qquad \text{Eq. 9-6}$$

where:

T = resultant tension at support, Newtons (pounds).
L_{max} = maximum span, meters (feet).

The above formulae can be used to determine the maximum possible span given a maximum tension at supports. This is most useful when dealing with river crossings, etc.

9.12 Sag and Tension Relationships: The relationships given below are useful for understanding the sag tension relationships for conductors:

9.12.1 Level Span Sags: The approximate "parabola method", Equation 9-7 below, is helpful in solving some sag and tension problems in span lengths below 300 meters (1,000 feet) or where sag is less than 5 percent of the span length.

$$S = \frac{w_c L^2}{8T_h} \qquad \text{Eq. 9-7}$$

where:

S = sag at center of span in meters (feet).
L = span length in meters (feet).
T_h = horizontal tension in Newtons (pounds).

The exact formula for determining sags is:

$$S = \frac{T_h}{w_c} \left(\cosh \frac{w_c L}{2T_h} - 1\right) \qquad \text{Eq. 9-8}$$

9.12.2 Inclined Span Sags: See Figure 9-6 for method of determining inclined span sags.

9.12.3 Tension: The conductor tension in a level span varies from a maximum value at the point of support to a minimum value at mid-span point.

The tension at the point of support is:

$$T = T_h + w_c S = T_h \cosh \frac{w_c L}{2T_h} \qquad \text{Eq. 9-9}$$

The value that is generally referred to, when the "tension" of a conductor is indicated, is usually the average of the tension at the support and the tension at mid-span. Thus:

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2} \qquad \text{Eq. 9-10}$$

where:
T_{avg} = average tension in Newtons (pounds).

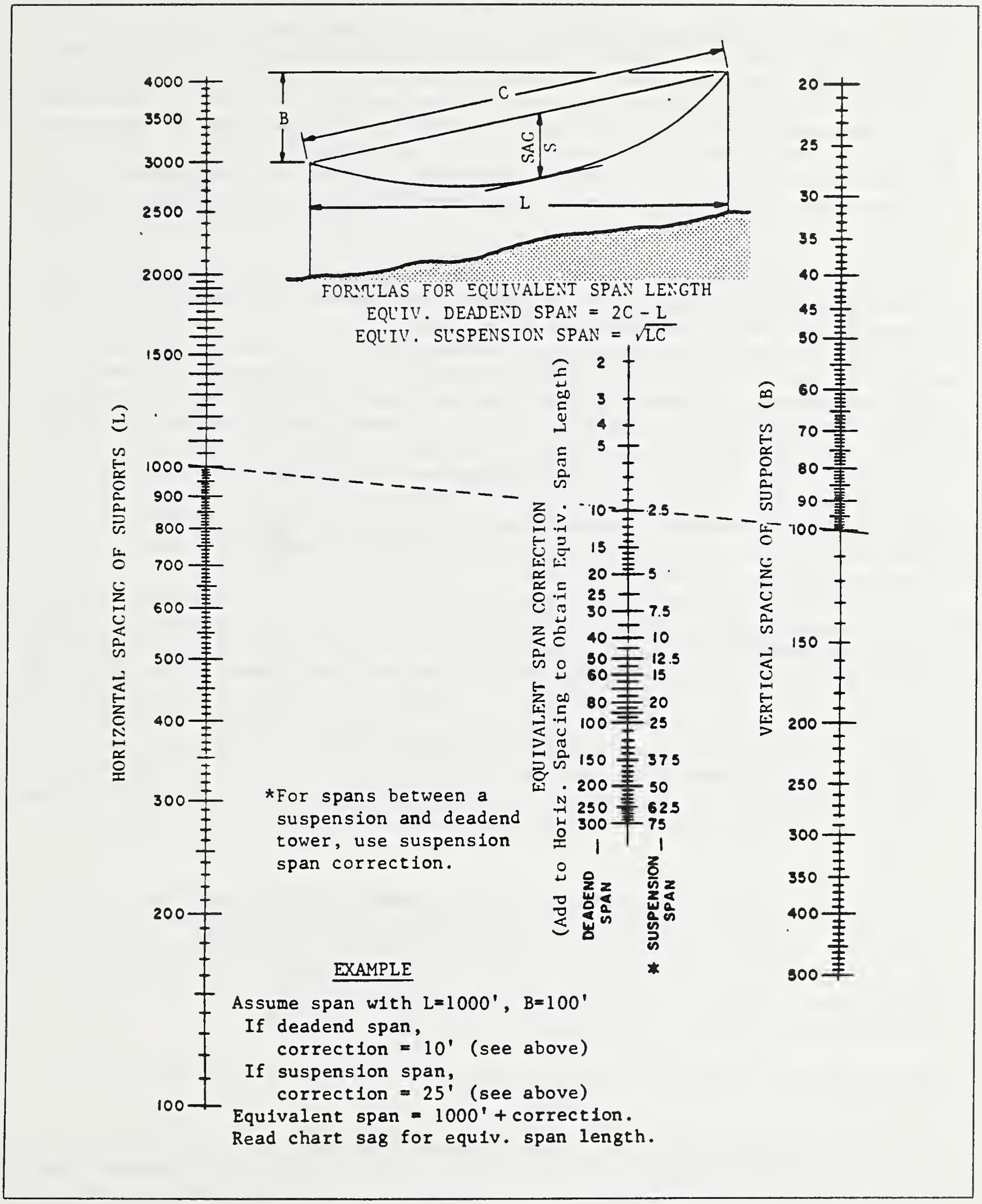


FIGURE 9-6: NOMOGRAPH FOR DETERMINING
LEVEL SPAN EQUIVALENTS OF NON-LEVEL SPANS

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9.13 Stringing Conductors

9.13.1 Tension Method (Preferred) for Stringing Conductors: Using this method, the conductor is kept under tension during the stringing process. Normally, this method is used to keep the conductor clear of the ground and obstacles which might cause conductor surface damage and clear of energized circuits. It requires the pulling of a light pilot line into the sheaves, which in turn is used to pull in a heavier pulling line. The pulling line is then used to pull in the conductors from the reel stands using specially designed tensioners and pullers. For lighter conductors, a lightweight pulling line may be used in place of the pilot line to directly pull in the conductor. A helicopter or ground vehicle can be used to pull or lay out a pilot line or pulling line. Where a helicopter is used to pull out a line, synthetic rope is normally used to attach the line to the helicopter and prevent the pilot or pulling line from flipping into the rotor blades upon release. The tension method of stringing is applicable where it is desired to keep the conductor off the ground to minimize surface damage, or in areas where frequent crossings are encountered. The amount of right-of-way travel by heavy equipment is also reduced. Usually, this method provides the most economical means of stringing conductor. The use of a helicopter is particularly advantageous in rugged or poorly accessible terrain.

Major equipment required for tension stringing includes reel stands, tensioner, puller, reel winder, pilot line winder, splicing cart and helicopter or pulling vehicle.

9.13.2 Slack or Layout Method: Using this method, the conductor is dragged along the ground by means of a pulling vehicle or the reel carried along the line on a vehicle and the conductor deposited on the ground. The conductor reels are positioned on reel stands or "jacks", either placed on the ground or mounted on a transporting vehicle. These stands are designed to support the reel on an arbor permitting it to turn as the conductor is pulled out. Usually a braking device is provided to prevent overrunning and backlash. When the conductor is dragged past a supporting structure, pulling is stopped and the conductor placed in sheaves attached to the structure before proceeding to the next structure.

This method is chiefly applicable to the construction of new lines in cases where maintenance of conductor surface condition is not critical and where terrain is easily accessible to a pulling vehicle. The method is not usually economically applicable in urban locations where hazards exist from traffic or where there is danger of contact with energized circuits, nor is it practical in mountainous regions inaccessible to pulling vehicles.

Major equipment required to perform slack stringing includes reel stands, pulling vehicle(s) and a splicing cart.

9.13.3 Stringing Conductors During Temperature Changes: An examination of conductor sag and tension tables will generally indicate the changes that take place in various span lengths for a change of conditions. For a given set of conditions, spans of various lengths may have a different rate of tension change with a change of loading or temperature. The ruling span tension of an unloaded conductor matches the tension of any other span at only one temperature. Large changes in temperatures during stringing require care

in matching average tensions in any section. It is desirable to complete stringing between deadends during minimum changes in temperature and at zero wind load. Where spans are supported by suspension insulators, each span will have an influence on adjacent spans such that no span can be considered independently of the remainder of spans in the same section between anchor structures. Change in temperature has a greater effect on short spans than loading does, while long spans are affected more by loading. However, in short spans a slight movement of supports results in substantial changes in tension while on longer spans relatively greater movement is required. The relation between adjacent span lengths therefore determines the movement required to equalize tension.

9.14 The Sagging of Conductors: It is important that the conductors be properly sagged in at the right stringing tension for the ruling span used. When installing conductors, a series of several spans is usually sagged in one operation by pulling the conductors to proper tension while they are supported on free rolling sheaves. To obtain the correct sags and to insure that the suspension insulators will hang vertically, the horizontal components of tension must be the same in all spans for a selected condition. In a series of spans of varying length, a greater sag tends to form in the long spans. On steep inclines the sheaves will deflect in the uphill direction and there will be a horizontal component of tension in the sheave itself. The horizontal component of tension in the conductor will therefore increase from one span to the next, as the elevation increases, by an amount equal to the horizontal component in the sheave. As a result, sags will proportionally decrease. In order to avoid this effect, it may be necessary to use a procedure called offset clipping whereby the point along the conductor at which it is attached to the insulator string is moved a specific distance down span from the point at which the conductor sits in the stringing block. See Figure 9-7 for further details on offset clipping.

It is important that the sags of the conductor be properly checked. It is best to do this in a series of level spans as nearly equal to the ruling span as possible.

For additional information, see:

A Guide to the Installation of Overhead Transmission Line Conductors, IEEE Standard 524-1980, IEEE, 1980.

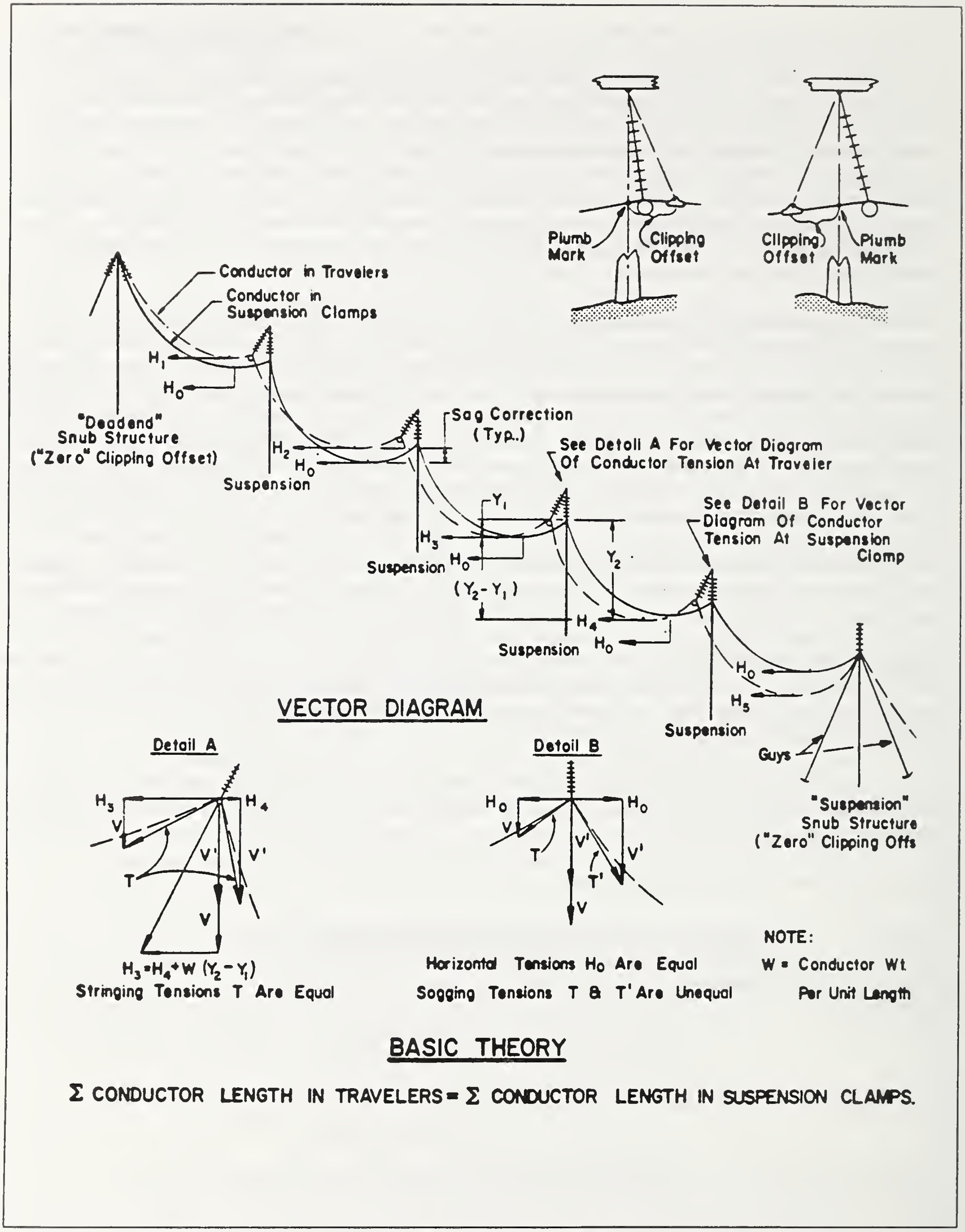

FIGURE 9-7: ANALYSIS FOR APPLICATION OF CLIPPING OFFSETS

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9.15 <u>Example 9-1</u>: Determination of Ruling Span: Determine the ruling span for the line segment given below using both the exact and approximate method.

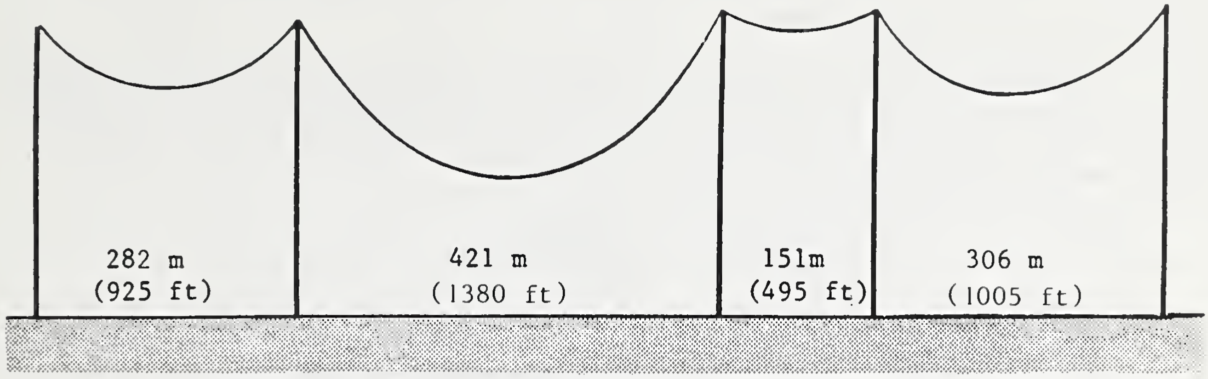


FIGURE 9-8: LINE SECTION FOR EXAMPLE 9-1

9.15.1 <u>Solution, Exact Method</u>:

$$RS = \sqrt{\frac{L_1{}^3 + L_2{}^3 + L_3{}^3 + \ldots + L_n{}^3}{L_1 + L_2 + L_3 + \ldots + L_n}} \qquad \text{Eq. 9-2}$$

$$RS = \sqrt{\frac{282^3 + 421^3 + 151^3 + 306^3}{282 + 421 + 151 + 306}} = 334 \text{ m}$$

$$RS = \sqrt{\frac{925^3 + 1380^3 + 495^3 + 1005^3}{925 + 1380 + 495 + 1005}} = 1094 \text{ ft.}$$

9.15.2 <u>Solution, Approximate Method</u>:

$$RS = L_{avg} + 2/3(L_{max} - L_{avg}) \qquad \text{Eq. 9-1}$$

$$L_{avg} = \frac{282 + 421 + 151 + 306}{4} = 290 \text{ m}$$

$$L_{max} = 421$$

$$RS = 290 + 2/3(421 - 290)$$

$$RS = 377 \text{ m}$$

$$L_{avg} = \frac{925 + 1380 + 495 + 1005}{4} = 951 \text{ ft.}$$

$$L_{max} = 1005$$

$$RS = 951 + 2/3(1380 - 951)$$

$$RS = 1237 \text{ ft.}$$

As mentioned in the text, the error between the exact and approximate methods of determining ruling span is caused by a rather significant error between the average and maximum span values.

9.16 <u>Example 9-2, Maximum Span Determination</u>: Determine the maximum span (for river crossings, etc.) for a 795 kcmil 26/7 ACSR conductor. Assume that under heavy loading district conditions, the conductor can be loaded up to 40 percent of its rated strength.

9.16.1 <u>Solution</u>: From the conductor tables in Appendix B, the rated strength of the conductor is 140,112 N (31,500 lbs.) and the weight of the conductor with 12.7 mm (1/2 in.) of radial ice is 30.56 N/m (2.0930 lbs/ft.). (Metric values converted from English values in table).

$$T = 140112(.4) = 56045 \text{ N}$$
$$T = 31500(.4) = 12600 \text{ lbs.}$$

$$L_{max} = 1.33 \frac{T}{w_c} \qquad \text{Eq. 9-6}$$

$$L_{max} = 1.33 \frac{56045 \text{ N}}{30.56 \text{ N/m}} = 2439 \text{ m}$$

$$L_{max} = 1.33 \frac{12600 \text{ lbs.}}{2.0930 \text{ lbs/ft.}} = 8007 \text{ ft.}$$

9.17 <u>Example 9-3, Determination of Tensions at the Mid Span Point and at the Point of Support</u>: A level 224 m (800 ft.) span of 795 kcmil 26/7 ACSR conductor has a sag of 6.70 m (21.95 ft.). The average tension value is 40,860 N (9,185 lbs.) and there is no ice or wind on the conductor. Determine the actual tension values at the mid span point and at the point of conductor support.

9.17.1 <u>Solution for the tension at mid span point</u>:

$$T_{avg} = \frac{T_h + T}{2} = T_h + \frac{w_c S}{2} \qquad \text{Eq. 9-10}$$

$$T_h = T_{avg} - \frac{w_c S}{2}$$

From the conductor tables in Appendix B, the weight of the conductor without ice is 15.971 N/m (1.0940 lbs/ft.).

$$T_h = 40860 \text{ N} - \frac{(15.971)(6.70)}{2}$$
$$T_h = 40806 \text{ N}$$
$$T_h = 9182 - \frac{(1.094)(21.95)}{2}$$
$$T_h = 9170 \text{ lbs.}$$

9.17.2 <u>Solution for the tension at support</u>:

$$T = T_h + w_c S \qquad \text{Eq. 9-9}$$
$$T = 40806 + (15.971)(6.70)$$
$$T = 40913 \text{ N}$$
$$T = 9170 + (1.094)(21.95)$$
$$T = 9194 \text{ lbs.}$$

10. PLAN-PROFILE DRAWINGS

10.1 General: The transmission line plan-profile drawings serve an important function in linking together the various stages involved in the design and construction of the line. Initially, the drawings are prepared based on a route survey to show the location and elevation of all natural and man-made features to be traversed by or which are adjacent to the proposed line, including ownership, which affect right-of-way, line design and construction. The drawings are then used to complete line design work such as structure spotting. During material procurement and construction, the drawings are used to control purchase of materials and serve as construction specification drawings. After construction, the final plan-profile drawings become the permanent record and right-of-way data, useful in line operation and maintenance or future modifications.

Accuracy, clarity, and completeness of the drawings should be maintained, beginning with initial preparation, to insure economical design and correct construction. All revisions made subsequent to initial preparation and transmittal of drawings should be noted in the revision block by date and brief description of revision. Originals of the plan-profile drawings, revised for as-built conditions, should be filed by the borrower for future reference.

10.2 Drawing Preparation: Adequate control of field survey, including ground check of aerial survey, and the proper translation of data to the plan-profile drawings are of utmost importance. Errors which occur during this initial stage will affect line design because a graphical method is used to locate the structures and conductor. Normally, plan-profile sheets are prepared using a scale of 61 meters (200 feet) to the inch horizontally and 6 meters (20 feet) to the inch vertically. On this scale, each sheet of plan-profile can conveniently accommodate about 1.6 kilometers (1 mile) of line with overlap to connect the end span on adjacent sheets. For lines with abrupt ground terrain and to minimize breaks in elevation view, a scale of one inch equal to 122 meters (400 feet) horizontally and one inch equal to 12 meters (40 feet) vertically may be used. The comparable metric scales would be: 1 cm = 50 m and 1 cm = 5 m.

A sample format for plan-profile drawing is shown by Figure 10-1, with units and stationings in U.S. customary units. Increase in stationing and structure numbering usually proceeds from left to right with the profile and corresponding plan view on the same sheet. Drawings prepared in ink on mylar or tracing cloth will provide a better permanent record; however, structure spotting initially should be done in pencil on plan-profile drawing paper and transferred to the base tracings after the drawings are approved and the line is released for construction.

Conventional symbols used to denote features on the drawings are shown in Figure 10-2. Existing features to be crossed by the transmission line, including the height and position of power and communication lines, should be shown and noted by station and description in both the plan and profile views. The magnitude and direction of all deflection angles in the line should be given and referenced by P.I. station in plan and elevation. In rough terrain, broken lines representing side-hill profiles should be plotted to assure

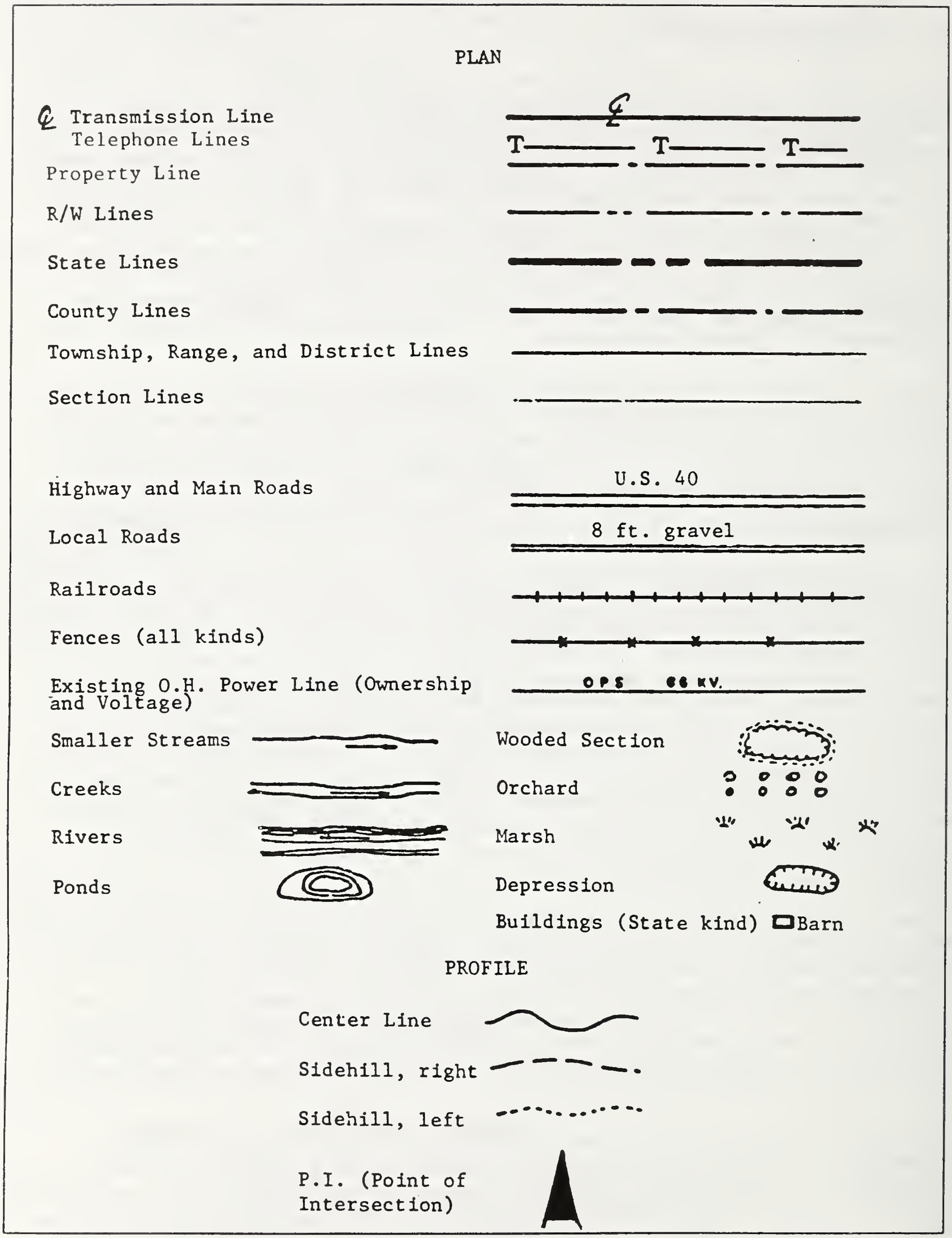


FIGURE 10-2: CONVENTIONAL SYMBOLS FOR PLAN-PROFILE

adequate conductor-ground clearances and pole height. A drawing title block should identify the line, give the stations covered by the sheet, and also include space for recording the personnel and dates involved in various stages of drawing preparation, line design, checking, approval, and revisions.

10.3 Sag Template: The sag template is a scaling device used for structure spotting and shows the vertical position of conductor (or ground wire) for specified design conditions . A sample of the conductor sag template is shown by Figure 10-3. It is used on plan-profile drawings to determine graphically the location and height of supporting structures required to meet line design criteria for vertical clearances, insulator swing, and span limitations. The sag template permits alternate layout for portions of the line to be investigated and thereby aids in optimizing line design for economy.

Generally, the conductor sag curves control the line design. The sag template for the overhead ground wire is used to show its position in relationship to the conductors for special spans or change in conductor configuration. Also, uplift condition at the overhead ground wire may be checked by using its cold curve.

10.3.1 Sag Template Curves: The sag template should include the following sag curves based on the design ruling span:

a. Hot (Maximum Sag) Curve: Maximum operating temperature, no ice, no wind, final sag curve. Used to check for minimum vertical clearances (or if maximum sag occurs under an icing condition, this value should be used for the sag template).

b. Cold Curve: Minimum temperature, no ice, no wind, initial sag curve. Used to check for uplift and insulator swing.

c. Normal Curve: 16°C (60°F), no ice, no wind, final sag curve. Used to check normal clearances and insulator swing.

The curves below are also used to locate the low point of sags and determine the vertical span lengths as illustrated by Figure 10-5. The curve intersection with the vertical axis line represents the low point position of sag in Figure 10-3.

Conductors of underbuild lines may be of different types or sizes than the transmission conductor. The hot curve of the lowest distribution conductor should be used for checking ground clearance. Cold curves may be required for each size of conductor to check for uplift or insulator swing.

10.3.2 Sag Template Design: For a given conductor, ruling span, design condition and temperature, sag values needed to construct the template are available from the conductor manufacturer or may be determined using the graphic method referred to in Section 9.8 of Chapter 9. The template should

CONDUCTOR: 336.4 kcmil ACSR (26/7)
RULING SPAN: 152.4 m (500 ft)
MAX. DESIGN TENSION: 25,737 N (5786 lb.)
DESIGN LOADING: 1.27 cm ice, 191.5 pa wind @ -17.8°C
1/2 in. ice, 4 psf wind @ 0°F

SCALE: HORIZONTAL 1" = 61 m (200 ft)
VERTICAL 1" = 6.1 m (20 ft)

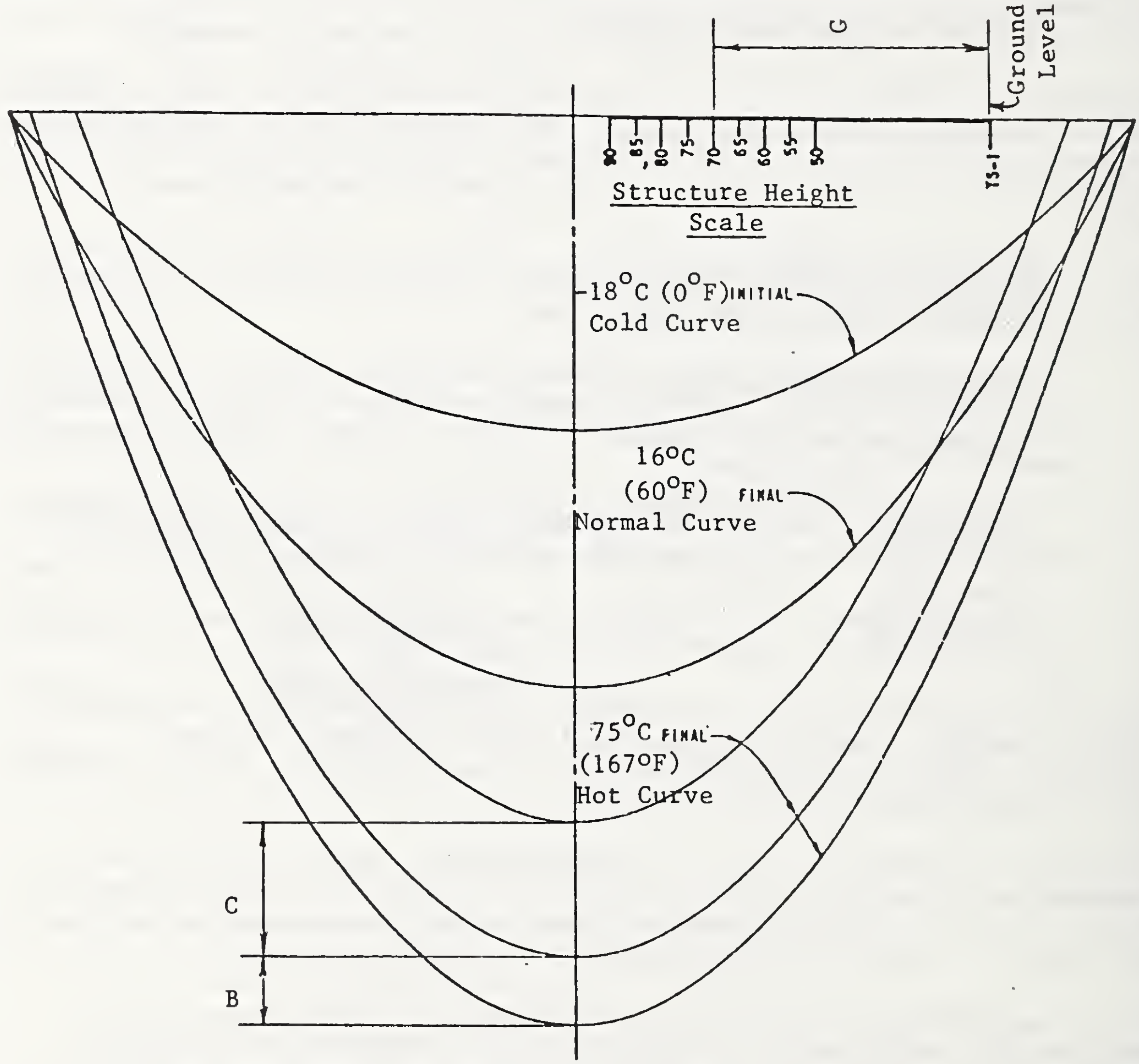


FIGURE 10-3: SPECIMEN SAG TEMPLATE FOR CONDUCTOR
(REDUCED SIZE - DO NOT SCALE)

be made to include spans three or four times as long as the normal level ground span to allow for spotting structures on steep terrain.

The form of the template is based on the fact that at the time when the conductors are installed, the horizontal tensions must be equal in all level and inclined spans if the suspension insulators are plumb in profile. This is also approximately true at maximum temperature. To obtain values for plotting the sag curves, sag values for the ruling span are extended for spans shorter and longer than the ruling span. Generally for spans up to 305 meters (1000 feet), it is sufficiently accurate to assume that the sag is proportional to the square of the spans if more accurate computed sag values are unavailable. The sag values used for the template may be determined as follows:

a. For the ruling span and its sag under each appropriate design condition and temperature, calculate other sags by the relationship:

$$S = \left(\frac{L}{RS}\right)^2 (S_{RS}) \qquad \text{Eq. 10-1}$$

where:

S = sag of other span in m (ft).
S_{RS} = sag of ruling span in m (ft).
L = length of other span in m (ft).
RS = length of ruling span in m (ft).

b. Apply catenary sag correction for long spans having large sags.

The template should be cut to include a minimum of 0.3 meters (1 foot) additional clearance than given in Table 4-1 in Chapter 4 to account for possible minor shifts in structure location and for error in the plotted profile. Where the terrain or the surveying method used in obtaining ground profile are subject to greater unknowns or tolerances, the 0.3 meters (1 foot) additional clearance should be increased accordingly. The vertical offset between the upper two maximum-temperature (hot) curves is equal to the total required clearance, including the specified additional clearance. It is shown as dimension "C" in Figures 10-3 and 10-4. The minimum temperature and the 16°C (60°F) curves may be placed in any convenient location on the template.

A sag template drawing similar to Figure 10-3 made to the same scales as the plan-profile sheets and for the specified conductor, ruling span, and loading condition should be prepared as a guide for cutting the template. A new template should be prepared for each line where there is any variation in voltage, conductor size, loading condition, design tension, or ruling span. A change in any one of these factors may affect the design characteristics of the template.

10.3.3 <u>Sag Template Construction</u>: The sag template should be made of dimensionally-stable transparent plastic material. A contrasting colored material, for example red, is very helpful when the template is used to check plan-profile drawings which are blueprints.

The curves are first plotted on paper using the correct scales and then reproduced or copied on the plastic material. To cut a template, the

transparent material is fastened securely over the sheet and the centerline and upper curves are etched lightly by a sharp-pointed steel scriber. The outside edges of the template should be etched deeply so that the template can be easily broken out and the edges sanded smooth. Structure height scales may also be drawn or etched on the sag template or a separate template for determining the pole height required for each type of structure used. The etched lines should be filled with ink to make them easier to see when the template is used.

Conductor size, design tension and loading condition, ruling span and descriptive data for each curve should be shown on the template.

10.4 Structure Spotting:

10.4.1 General: Structure spotting is the design process which determines the height, location, and type of consecutive structures on the plan-profile sheets. Actual economy and safety of the transmission line depends on how well this final step in the design is performed. The structure spotting should closely conform to the design criteria established for the line. Constraints on structure locations and other physical limitations encountered may prevent structure spotting of structures at optimum locations. Success of the effort to minimize or overcome these special conditions can be judged by how closely the final line layout follows the original design parameters.

Ideally, the desired properties of a well-designed and economical line layout are:

a. Spans approximately uniform in length, equal to or slightly less than the design ruling span. Generally, differential conductor tensions are minimized and may be ignored if adjacent span lengths are kept below a ratio of 1.5 to 1.

b. Maximum use of the basic structure of equal height and type. The basic structure is the pole height and class which has been selected as the most economical structure for the given design condition.

c. The shape of the running conductor profile, also referred to as the grading of the line, should be smooth. If the conductor attachment points at the structures lie in a smooth-flowing curve, the loadings are equalized on successive structures.

10.4.2 For a generally level and straight line with few constraints on structure locations, the above stated objectives do not conflict and can be readily achieved. Greater skill and effort are needed for lines with abrupt or undulating ground profile and where constraints on structure location exist. Examples of these conditions are high or low points in the profile and features such as line angle points, crossings over highway, railroad, water, power and communication lines, and ground with poor soil conditions. Structure locations and heights are often controlled or fixed by these special considerations. Alternate layouts between fixed locations may be required to determine the best arrangement based on factors of cost and effective design.

The following design factors are involved in structure spotting and are covered in the chapters of this manual:

a. <u>Vertical Clearances</u>
- Basic, level ground
- Crossings
- Sidehill
- Underbuild

b. <u>Horizontal Clearances</u>
- For insulator sideswing condition
- To edge of right-of-way, vertical obstructions and steep sidehills

c. <u>Uplift</u>

d. <u>Horizontal or Vertical Span Limitations Due to</u>:
- Vertical sag - clearance requirement
- Conductor separation
- Galloping
- Structure strength
- Crossarm strength

e. <u>Angle and Deadend</u>
- Guying arrangements
- Guy anchors

10.4.3 <u>Preparation</u>: The following are necessary for structure spotting:

a. Plan-profile drawings of the transmission line.

b. Sag template of the same scale as the plan-profile prepared for the design temperatures, loading condition, and ruling span of the specified conductor and overhead ground wire.

c. Table of minimum conductor clearances over ground features and other overhead lines (Chapter 4).

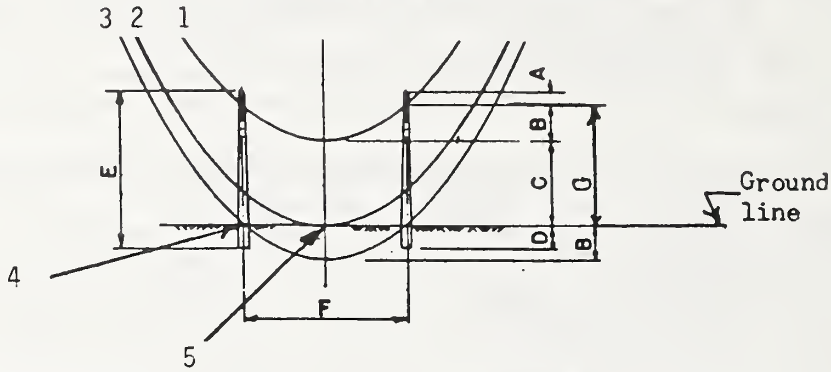
d. Insulator swing charts (Chapter 7).

e. Horizontal and vertical span limitations due to clearance or strength requirements (Chapters 8, 9, and 13).

f. Guy arrangement and anchor requirements for angle and deadend structures (Chapter 14).

A height scale prepared for each structure type will aid in height determination. Supporting calculations should be summarized in chart or tabular form to facilitate application during structure spotting. This is especially advisable for the standard suspension structure which has a greater range of pole height and class, as well as bracing variations for H-frame structures. Selection of the proper pole may be affected by different criteria, changing from span controlled by clearance to span limited by pole strength for different pole height and class or bracing.

10.4.4 Process of Spotting: The process of spotting begins at a known or established conductor attachment point such as a substation take-off structure. For level terrain, when a sag template is held vertically and the ground clearance curve is held tangent to the profile, the edge of the template will intersect the profile at points where structures of the basic height should be set. This relation is illustrated for a level span in Figure 10-4. Curve No. 1 represents the actual position of the lowest conductor, offset by the required total ground clearance, "C".



Hot Curves (Maximum Sag)

Curve 1 -Lowest Conductor Sag Position
2 -Basic Ground Clearance Curve
3 -Edge of Template or Reference Line
Point 4 -Intersection Locates Pole of Basic Height
5 -Tangent to Ground Profile

A = Dimension from top of pole to point of attachment of lowest conductor.
B = Sag in level ground span.
C = Total ground clearance.
D = Setting depth of pole.
E = Length of pole.
F = Level ground span.
G = Dimension from ground to point of attachment of lowest conductor.

FIGURE 10-4: APPLICATION OF SAG TEMPLATE - LEVEL GROUND SPAN.

The point where Curve No. 3 intersects the profile determines the location of the next structure and is marked by drawing an arc along the edge of the template where it intersects the profile. The template should then be shifted and adjusted so that with the opposite edge of the template held on the conductor attachment point previously located with the clearance curve again barely touching the profile. The process is repeated to establish the location of each succeeding structure. After all structures are thus located, the structures and lowest conductor should be drawn in.

The above procedure can be followed only on lines that are approximately straight and which cross relatively flat terrain with the basic ground clearances. When line angles, broken terrain, and crossings are encountered, it may be necessary to try several different arrangements of structure locations and heights at increased clearances to determine the arrangement that is most satisfactory. The special considerations often fix or limit the structure locations and it is advisable to examine the profile for several span lengths ahead for these conditions and adjust the structure spotting accordingly. Sometimes, a more balanced arrangement of span lengths is

achieved by moving ahead to one of these fixed locations and working back. The relationship of the ground clearance and conductor curves is also used for spans other than level-ground spans by shifting the sag template until ground profile touches or is below the clearance curve with the previously established conductor attachment point (normally, the left) positioned on the conductor curve. The conductor curve would then indicate the required conductor height for any selected span. Structure height may be determined by scaling or use of the proper structure height template, taking into account the change in the embedded pole length for poles other than the basic pole. Design limitations due to clearance or structure strength should be observed.

10.4.5 Crossings: For spans crossing features such as highway and power lines with different clearance requirements than the normal clearance, the ground clearance curve should be adjusted accordingly. In California, adequate ground clearance must be maintained over all crossings over railroads, major highways, major communication and power lines under a broken conductor condition in either of the spans adjacent to the crossing span. Other states are governed by the NESC, which does not require the broken conductor condition in the latest edition. The increase in sag due to a broken conductor in an adjacent span is usually significant only where suspension- type structures are used at crossings and for voltage at 230 kV or above. Where tension structures are used and for suspension structures at lower voltages, the sag increase normally will not seriously affect the clearance.

10.4.6 Insulator Sideswing - Vertical Span: Horizontal conductor clearances to supporting structure are reduced by insulator sideswing under transverse wind pressure. This condition occurs where the conductor is supported by suspension-type insulators. Conductors supported by pin-type, post, or tension insulators are not affected and horizontal clearance of the deflected conductor position within the span becomes the controlling factor. Suspension insulators also deflect laterally at line angle locations due to the transverse component of conductor tension.

Chapter 7 covers the preparation of insulator swing charts. At each structure location the charts are used to determine if insulator swing is within the allowed limit for the vertical and horizontal spans and line angle conditions. For suspension insulators supported on horizontal crossarms, a minimum vertical span must be maintained to avoid excessive sideswing. For insulators attached directly to the pole and for some types of angle structures, the vertical span must not exceed a maximum value as indicated by the chart to maintain adequate clearance.

The vertical span is the distance between the conductor low points in spans adjacent to the structure and horizontal span being the average value of the adjacent spans. Where conductor attachments are at different elevations on adjacent structures, the low point is not a mid-span and will shift its position as the temperature changes. This can be readily seen by comparing the low point for the hot curve with its position for the cold curve. The vertical span value used to check the insulator swing should be based on the low point position which yields the most critical condition for the structure type.

Where minimum vertical span or uplift is the concern, the cold curve should be used. The normal temperature is more critical and should be used if the vertical span is limited by a maximum value. Figure 10-6 shows some examples of the relationship of conductor low points and vertical spans which may occur in a line profile.

If insulator swing is unacceptable, one of the following corrective steps, in order of preference, is recommended:

a. Relocate structures to adjust horizontal-vertical span ratio.

b. Increase structure height or lower adjacent structures.

c. Use a different structure, one with greater allowable swing angle or a deadend structure.

d. Add weight at insulators to provide the needed vertical force.

10.4.7 Uplift: Uplift is defined as negative vertical span and is determined by the same procedure as vertical span. On steeply inclined spans when the cold sag curve shows the low point to be beyond the lower support structure, the conductors in the uphill span exert upward forces on the lower structure. The amount of this force at each attachment point is related to the weight of the loaded conductor from the lower support to the low point of sag. Uplift exists at a structure when the total vertical span from the ahead and back spans is negative, as shown by Structure No. 4 in Figure 10-6, while

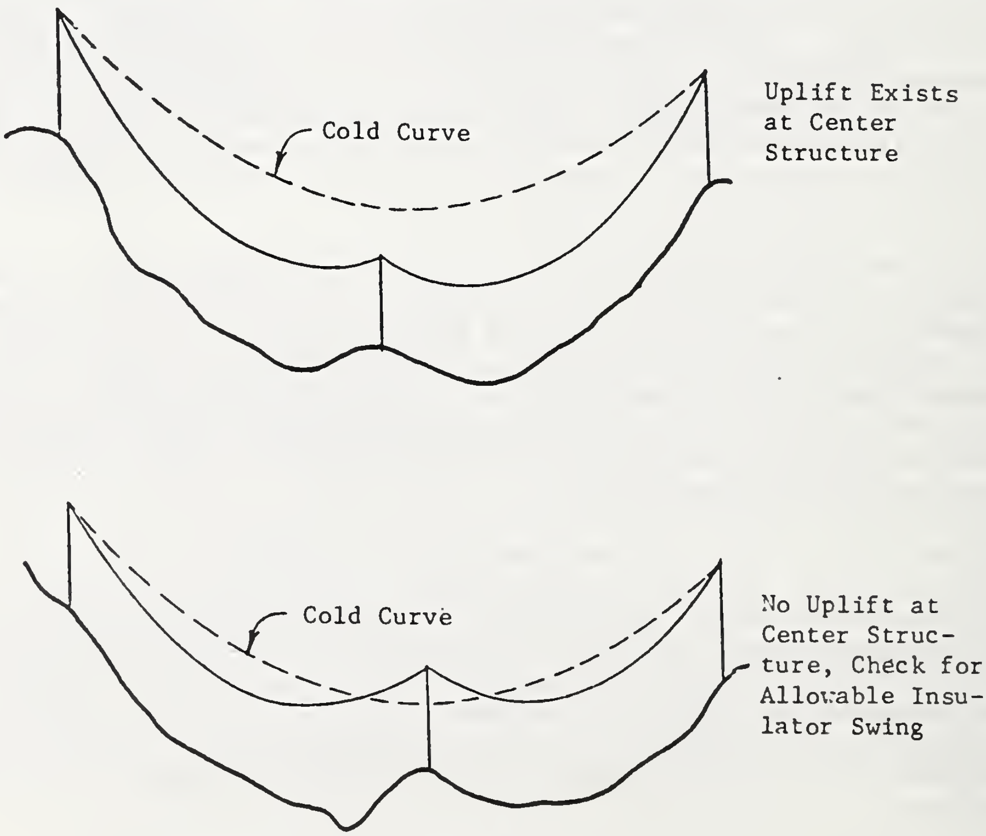


FIGURE 10-5: CHECK FOR UPLIFT

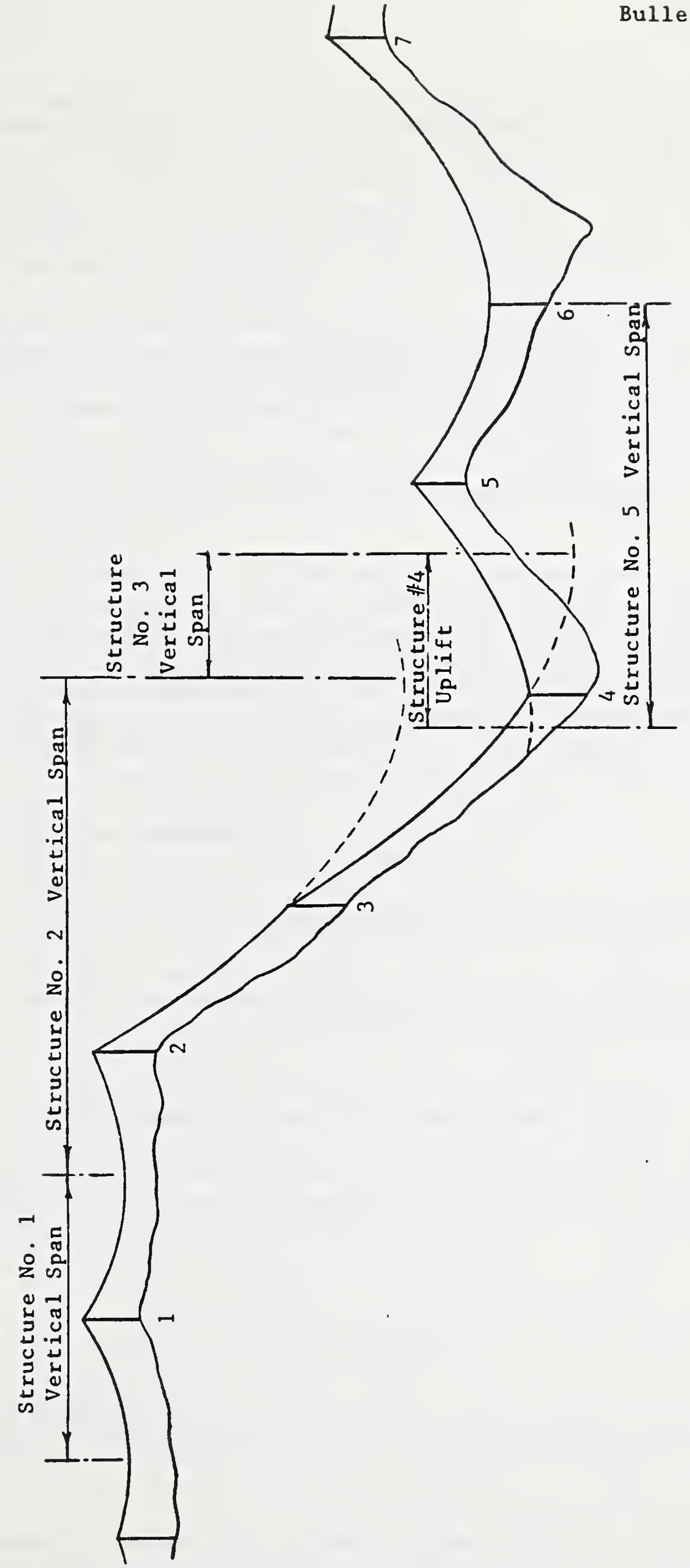


FIGURE 10-6: SAG LOW POINT, VERTICAL SPANS, AND UPLIFT

no net uplift occurs at Structure No. 3. Uplift must be avoided for suspension, pin-type, and post insulator construction. For structures with suspension insulators, the check for allowable insulator swing is usually the controlling criteria on vertical span. A rapid method to check for uplift is shown by Figure 10-5. There is no danger of uplift if the cold curve passes below the point of conductor support on a given structure with the curve on the point of conductor support at the two adjacent structures.

Designing for uplift or minimizing its effects is similar to the corrective measures listed for excessive insulator swing, except that adding of excessive weights should be avoided. Double deadends and certain angle structures can have uplift as long as the total force of uplift does not approach the structure weight. If it does, hold-down guys are necessary.

Care should be exercised to avoid locating structures that result in poor line grading.

10.4.8 Other Considerations: If maximum conductor tension of other limits are not exceeded, it may be preferable to use one long span with adequate conductor separation over a depression in the profile rather than use two short spans with a deadend structure at the bottom of the depression which may be subjected to considerable uplift at minimum conductor temperature. Also, poorer soil foundation conditions usually exist in the depression. Care must be exercised at locations where the profile falls sharply away from the structure to see that the maximum allowable vertical span as limited by the strength of the crossarm or insulator is not exceeded. Structure No. 2 in Figure 10-6 illustrates this condition. For maximum accuracy in the heavy or medium loading zone, the vertical span for this purpose should be determined with a curve made for the sag under ice load, no wind, at 0°C (32°F). For most conductors, however, the maximum temperature final sag curve will closely approximate the curve for the ice-loaded conductor, and it may be used when checking for maximum vertical span. For guyed structures, the maximum vertical loads added to the vertical components from guy loads should be checked against the buckling strength of the pole.

The profile in rough country where sidehills are encountered should be prepared so that the actual clearances under the uphill and downhill conductor may be checked. For some long spans it may be necessary to check sidehill clearance with the conductors in their maximum transverse swing position. H-frame type structures installed on sidehills may require different pole heights to keep the crossarm level or one pole may be set a greater than normal setting depth.

Structures with adequate longitudinal strength (normally guyed deadends) are required at locations where longitudinal loading results from unequal line tensions in adjacent spans. For lines subject to heavy ice and high wind conditions and with long, uninterrupted section of standard suspension structures, consideration should be given to include some structures with in-line guys or other means to contain and prevent progressive, cascading-type failure.

This is especially important for H-frame type structures with lower strength in the longitudinal direction when compared with its transverse strength and for lines without overhead ground wire which tends to restrain the structure

from collapsing longitudinally. A maximum interval of 8 to 16 km (5-10 miles) is suggested between structures with adequate longitudinal capacity, depending on the importance of the line and the degree of reliability sought.

10.5 Other Design Data: The conductor and ground wire sizes, design tensions, ruling span, and the design loading condition should be shown on the first sheet of the plan-profile drawings. For completeness, it is preferable that these design data be shown on all sheets. A copy of the sag template reproduced on the first sheet could serve as a record of design in case the template is misplaced or lost. Design data for underbuild and portions of the line where a change in design parameters occurs should similarly be indicated. The actual ruling spans between deadends should be calculated and noted on the sheets. This serves as a check that the actual ruling span has not deviated greatly from the design ruling span. The significance of this deviation is also covered in the ruling span section of Chapter 9. Where spans are spotted at lengths under one-half or over twice the ruling span, deadending may be required.

As conductor sags and structures are spotted on each profile sheet, the structure locations are marked on the plan view and examined to insure that the locations are satisfactory and do not conflict with existing features or obstructions. To facilitate preparation of a structure list and the tabulation of the number of construction units, the following items, where required, should be indicated at each structure station in the profile view:

a. Structure type designation
b. Pole height and class
c. Pole top, crossarm, or brace assemblies
d. Pole ground unit
e. Miscellaneous hardware units (vibration dampers at span locations)
f. Guying assemblies and anchors

The number of units or items required should be shown in parenthesis if greater than one. Successive plan-profile sheets should overlap, with the end structure on a sheet shown as a broken line on the following sheet for continuity and to avoid duplicate count. The number and type of guying assemblies and guy anchors required at angle or deadend locations, based on guying calculations or application charts, should also be indicated. Design check, line construction, and inspection are facilitated if an enlarged guying arrangement, showing attachments and leads in plan and elevation, is added on the plan-profile sheet adjacent to each guyed structure. Any special notes or large-scale diagrams necessary to guide the construction should be inserted on the plan-profile sheet. This is important at locations where changes in line design or construction occur, such as a slack span adjacent to a substation, line transposition, or change in transmission and underbuild circuits.

10.6 Drawing Check and Review: The completed plan-profile drawings should be checked to insure that the line meets the design requirements and criteria originally specified, adequate clearances and computed limitations have been maintained, and required strength capacities have been satisfied. The sheets should be checked for accuracy, completeness, and clarity. Figure 10-7 is a Specimen Check List for review of plan and profile sheets. An abbreviated list of key items may be prepared and imprinted on each sheet by an inked stamp to aid in recording the check and review process.

Project ______________________, Date ______________

Line ______________________, Voltage ______________ kV

Plan & Profile Drawing Nos. __________, Checked by ______________

Loading Zone ____________. Ruling Span ____________. Ft.

Conductor ______________________, Design Tension ______________

OHGW ______________________, Design Tension ______________

Underbuild ______________________, Design Tension ______________

	Sheet Number											
	PLAN:											
	Property Information											
	Swamps, Rivers, Lakes, etc.											
	R/W Data, Boundaries											
	Location, Buildings, Schools, etc.											
	Other Utilities											
	Obstructions, Hazards											
	Roads											
	Angles, P.I., Bearing of Centerline											
	PROFILE:											
	Horizontal Span Length											
	Vertical Span Length											
	Type Structure											
	Pole Strength											
	Pole Height											
	Pole Foundation Stability											
	Crossarm Strength											
	Conductor Clearance:											
	To Ground or Side Hill											
	To Support and Guys											
	To Buildings											
	Crossing											
	Conductor Separation											
	Conductor Tension Limitations											
	Climbing or Working Space											
	Guy Tension											
	Guy Lead & Height											
	Anchors											
	Insulator Swing or Uplift											
	Tap Off, Switches, Substations											
	Underbuild											
	Code Requirements											

Remarks: ____

FIGURE 10-7: SPECIMEN CHECK LIST FOR REVIEW OF PLAN AND PROFILE

11. LOADINGS AND OVERLOAD FACTORS

11.1 General: The strength that is to be designed into a transmission line depends to a large extent on the wind and ice loads that may be imposed on the conductor, overhead ground wire, and supporting structure. These loadings are related generally to the geographical location of the line.

When selecting appropriate design loads, the engineer should evaluate climatic conditions, previous line operation experience, and the importance of the line to the system. Conservative load assumptions should be made for a transmission line which is the only tie to important load centers.

11.2 Loads

11.2.1 NESC Loading Districts: The NESC divides the country into three weather or loading districts, as shown in Figure 11-1.

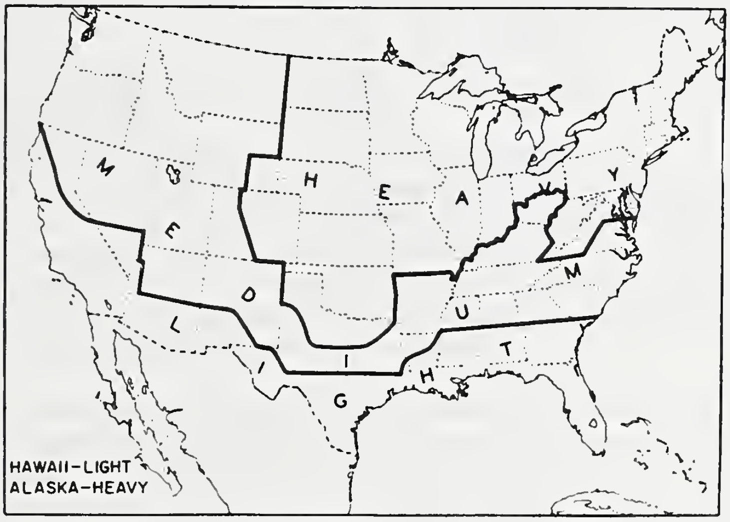


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FIGURE 11-1

The minimum design conditions associated with each loading district are given in Table 11-1. The constants in this table are to be added to the vector resultant for tension calculations only.

TABLE 11-1
NESC LOADING DISTRICTS

	Design Temperature °C (°F)	Radial Ice Thickness cm (in.)	Wind Pressure* pascals (psf)	Constants** N/m(lbs/ft)
Heavy Loading	-17.8 (0°)	1.27 (1/2")	191.5 (4)	4.4 (.30)
Medium Loading	- 9.4 (15°)	.63 (1/4")	191.5 (4)	2.9 (.20)
Light Loading	- 1.1 (30°)	0 (0")	430.9 (9)	.73 (.05)

*For cylindrical surfaces only.
**For tension calculations only.

Designing to these minimum requirements may not be sufficient. Extreme winds and special ice conditions should be investigated. The determination of an appropriate design load to account for extreme winds is easier than determining a heavy ice design load. Whereas meteorological data may be available on high winds, little data is available on extreme ice loads. Heavy ice combined with a relatively high wind should also be considered.

11.2.2 Extreme Ice: In certain areas of the country heavy ice may be predominant. The engineer should review the experience of utilities or cooperatives in the area of the line concerning ice conditions and determine the number and frequency of outages due to ice storms, and the design assumptions used for existing lines in the area. From this data, the engineer can reasonably determine if a heavy ice condition greater than what is required by the NESC needs to be included in the design.

If historical data on icing conditions is lacking, the engineer should consider designing the line for extreme wind conditions without ice, and loading zone conditions, and then calculate the maximum ice load the structure could sustain without wind. The designer would then evaluate whether or not he could "live" with this specific ice condition.

11.2.3 Extreme Winds: Although the NESC requires that structures over 60 ft. sustain high winds, REA recommends that all transmission lines meet extreme wind requirements. Figure 11-2 gives minimum horizontal wind speeds to be used in calculating loads. Linear interpolation should be used when considering locations between isotachs. Local meteorological data should also be evaluated in determining a design high wind speed. Table 11-2 relates wind speed to pressure for a cylindrical surface.

11.2.4 Longitudinal Loads: Unbalanced longitudinal loads on a line may occur because of a broken conductor, differential ice conditions on equal or unequal spans, stringing loads, or a change in ruling span. Traditionally, the standard tangent wood pole structures have not been designed for broken conductor longitudinal loads and have relied on the restraining capacity of deadends.

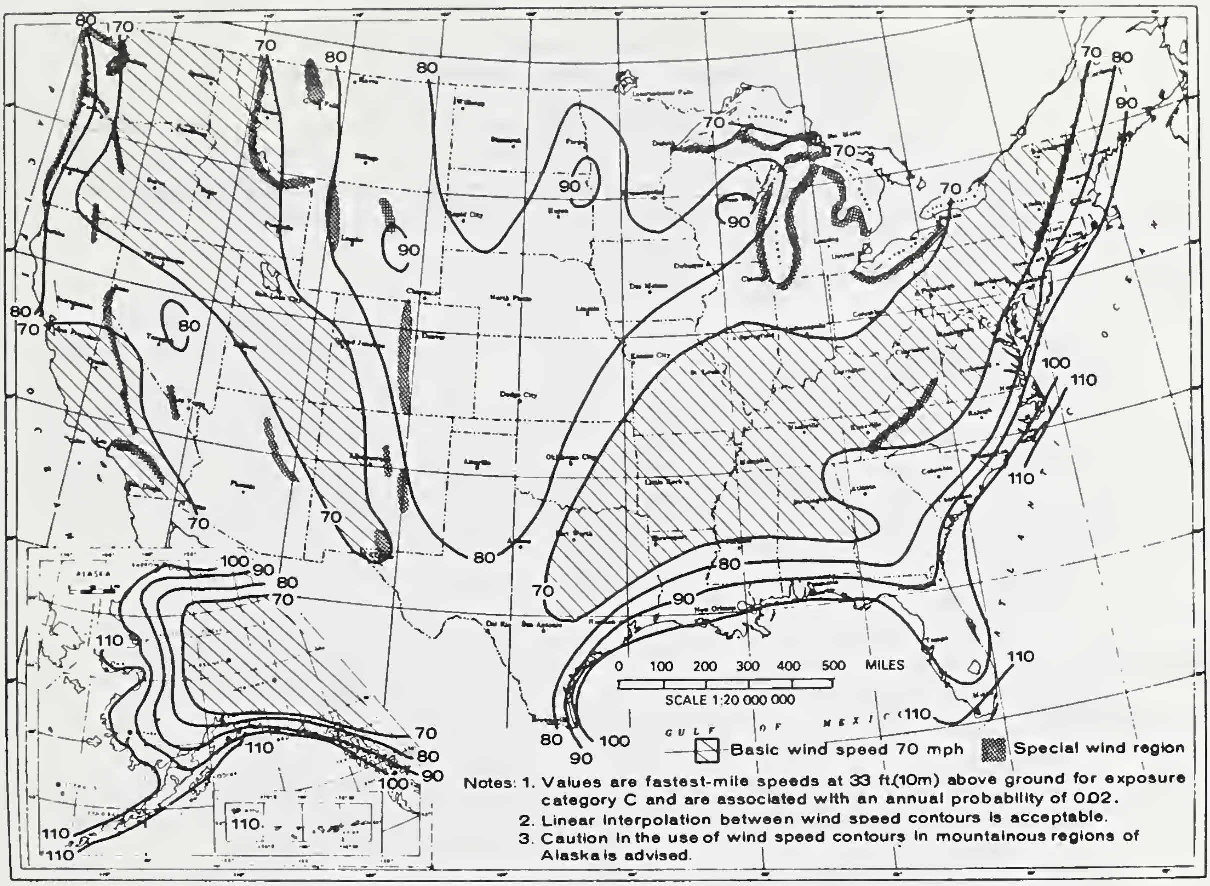


FIGURE 11-2 EXTREME WIND SPEED IN MILES PER HOUR AT 33 FT. ABOVE GROUND (50-YEAR MEAN RECURRENCE INTERVAL)

TABLE 11-2

Horizontal Wind Pressures on Cylindrical Surfaces

Wind Speed in m/s	(mi/h)	Wind Pressure in kPa	(lb/ft^2)
31	(70)	.60	(13)
36	(80)	.78	(16)
40	(90)	1.00	(21)
45	(100)	1.23	(26)
49	(110)	1.48	(31)

TABLE 11-3

REA GRADE B (NEW CONSTRUCTION)
RECOMMENDED OVERLOAD CAPACITY FACTORS
TO BE APPLIED TO NESC LOADING DISTRICTS LOADS

	Overload Capacity Factors		% Rated Ultimate Strength	
	NESC	REA	NESC	REA
WOOD POLES				
Vertical Loads	2.20	4		
Transverse Loads				
Wind	4.00	4		
Wire Tension				
At crossings	2.00	2		
Elsewhere	2.00	2		
Longitudinal Loads				
General	1.33	2		
Deadends	2.00	2		
CROSSARMS				
Vertical Loads	2.20	4		
Transverse Loads				
Wind	4.00	4		
Wire tension				
At crossings	2.00	2		
Elsewhere	2.00	2		
Longitudinal Loads				
General	1.33	2		
Deadends	2.00	2		
GUYS AND ANCHORS				
Vertical Loads	1.50	2	90%	100%
Transverse Loads				
Wind	2.50	4	90%	100%
Wire tension	1.65	2	90%	100%
Longitudinal Loads				
General	1.10	2	90%	100%
Deadends	1.65	2	90%	100%
GUY ATTACHMENTS				
Transverse Wind Loads	2.5	-		40%
Wire Tension Loads	1.65	-		40%
INSULATORS			(See Table 8-5)	
CONDUCTOR			(See Table 9-2)	

TABLE 11-4

RECOMMENDED OVERLOAD FACTORS TO BE APPLIED TO EXTREME WIND PRESSURES (NEW CONSTRUCTION)

	Overload Capacity Factors NESC	Overload Capacity Factors REA	% Rated Ultimate Strength NESC	% Rated Ultimate Strength REA
WOOD POLES AND CROSSARMS				
Vertical Loads	1.00	1.33		
Transverse				
Wind	1.33	1.50		
Wire Tension	1.33	1.33		
Longitudinal				
General	1.33	1.33		
Deadends	1.33	1.50		
GUYS, GUY ATTACHMENTS AND ANCHORS				
Transverse and Longitudinal Loads				
Wind	1.00	1.50	90%	100%
Wire tension	1.00	1.33	90%	100%

11.3 Overload Factors for Wood Pole Construction: Transmission lines are to be built to Grade B construction. In Table 11-3, the columns under the "REA" headings give the recommended minimum overload capacity factors to be applied to the light, medium, and heavy loading districts of the NESC in the design of guys, anchors, crossarms, and poles.

The recommended overload factors to be applied to extreme wind pressures are in Table 11-4. The factors are intended to take into account approximations made in the design and analysis, variability of wood, gusting on the structure, and increased wind velocity with height. In areas near the coast where transmission lines are subject to hurricane loads, the engineer should consider increasing the appropriate overload factors.

11.4 Alternate Method to Meet Strength Requirements: The 1990 edition of the NESC permits the use of an alternative method to meet minimum strength requirements. This alternate method separates the overload capacity factors into load factors and strength factors. The recommended load factors and strength factors found in Table 11-5 should be used in order to achieve comparable minimum strengths when using REA recommended overload capacity factors.

TABLE 11-5

GRADE B (NEW CONSTRUCTION)
RECOMMENDED ALTERNATE LOAD & STRENGTH FACTORS
TO BE APPLIED TO NESC DISTRICTS LOADS

WOOD POLES AND CROSSARMS	NESC	REA
STRENGTH FACTORS	.65	.65
LOAD FACTORS		
Vertical Loads	1.50	2.50
Transverse Loads		
Wind	2.50	2.50
Wire Tension		
At crossings	1.65	1.65
Elsewhere	1.65	1.65
Longitudinal		
General	1.00	1.33
Deadends	1.65	1.65
GUYS, GUY ATTACHMENTS AND ANCHORS		
STRENGTH FACTORS (For Guys)	.90	.65
(For Anchors)	N.S.	.65
(For Guy Attachments)	N.S.	.55
LOAD FACTORS		
Vertical Loads	1.50	2.50
Transverse Loads		
Wind	2.50	2.50
Wire Tension	1.65	1.33*
Longitudinal Loads		
In general	1.10	1.33
At deadends	1.65	1.33*

TABLE 11-6

RECOMMENDED ALTERNATE LOAD AND STRENGTH FACTORS
TO BE APPLIED TO EXTREME WIND PRESSURES

(As of this printing, use Table 11-4)

*Although this load factor is less than the NESC load factor, the combined load factor and strength factor is greater than Code.

12. FOUNDATION STABILITY OF WOOD POLES

12.1 General: Every structure standing above ground is subjected to lateral forces. In the case of wood transmission structures, it is desirable to depend on the earth to resist lateral forces. The embedded portion of a wood pole provides this resistance by distributing the lateral load over a sufficient area of soil. For wood poles, a properly selected embedment depth should prevent poles from kicking out. With time, single wood poles may not remain plumb. Leaning of wood pole structures is permitted, provided excessive angular displacements are avoided and adequate clearances are maintained.

The lateral forces which wood transmission structures are subjected are primarily due to wind and wire tension loads due to line angles. Longitudinal loads due to deadending or uniform ice on unequal spans should be examined to see how they affect embedment depths. Normally, flexible transmission structures are stabilized longitudinally by the overhead ground wire and the phase conductors.

The bearing and lateral earth capacity of soils depend on soil types and their characteristics such as internal friction, cohesion, unit weight, moisture content, gradation of fines, consolidation and plasticity. Most soils are a combination of a cohesive soil (clay) and a cohesionless soil (sand).

12.2 Site Survey

12.2.1 In deciding embedment depths for wood poles, economics dictate that few, if any, soil borings be taken if data and experience from previous lines are available. Numerous soil conditions will be encountered in the field. Although the soil conditions may closely resemble each other, they may have a wide range of strengths. The engineer, therefore, must identify areas or conditions where pole embedment depths in soil may have to be greater than the minimum depths of 10 percent, plus .6 meters or 2 feet. These areas include:

a. Low areas near streams, rivers, or other bodies of water where a high water table or a fluctuating water table is probable. Poles in a sandy soil with a high water table may "kick" out. Due to the lubricating action of water, frictional forces along the surface area of embedded poles are reduced. The legs of H-frames may "walk" out of the ground if neither sufficient depth nor bog shoes are provided to resist uplift. Guy anchors may fail if the design capacity does not consider the submerged weight of the soil.

b. Areas where the soil is loose such as soft clay, poorly compacted sand, pliable soil, or soil which is highly organic in nature.

c. Locations where higher safety is desired. This may be at locations of unguyed small angle structures where a portion of the load is relatively permanent in nature, or at river, line, or road crossings.

d. Locations where poles are set adjacent to or on steep grades.

12.2.2 A field survey is necessary in order to judge whether a soil is "good", "average", or "poor". There are several economical methods of making a field survey for wood transmission lines. The engineer may use a hand auger, light penetrometer, or torque probe. The meaning of firm, soft, dense, loose, etc., may have different connotations. The following table will help in the understanding of these terms:

TABLE 12-1
CLASSIFICATION OF SOILS BASED
ON FIELD TESTS

Cohesive Soils (Clays)

Term	Field Test
Very soft	Squeezes between fingers when fist is closed
Soft	Easily molded by fingers
Firm	Molded by strong pressure of fingers
Stiff	Dented by strong pressure of fingers
Very stiff	Dented only slightly by finger pressure
Hard	Dented only slightly by pencil point

Cohesionless (Sands)

Term	Field Test
Loose	Easily penetrated with a 1.27 cm (1/2 in.) reinforcing rod pushed by hand
Firm	Easily penetrated with a 1.27 cm (1/2 in.) reinforcing rod driven with a 2.27 kg (5 lb.) hammer
Dense	Penetrated .3048 meters (1 ft.) with a 1.27 cm (1/2 in.) reinforcing rod with a 2.27 kg (5 lb.) hammer
Very dense	Penetrated only a few inches with a 1.27 cm (1/2 in.) reinforcing rod driven with a 2.27 kg (5 lb.) hammer

12.3 Pole Stability

12.3.1 In addition to local experience, the following method is useful in determining depth of embedment:

Metric

$$P = \frac{S_e D_e^{3.75}}{L - .6096 - .662 D_e}$$

English

$$P = \frac{S_e D_e^{3.75}}{L - 2. - .662 D_e} \quad \text{(Eq. 12-1)}$$

where:

P = horizontal force in Newtons (pounds), .6096 meters (2 feet) from the top that will just overturn the pole.
S_e = soil constant.
S_e = 16,340 for good soils (140)
S_e = 8,170 for average soils (70)
S_e = 4,085 for poor soils (35)

D_e = embedment depth of pole in meters (feet).
L = total length of pole in meters (feet).

Figures 12-1 to 12-3 are plots of the above equation. For an equivalent horizontal load 2 feet from the top (total ground line moment divided by the lever arm to .61 meters (2 feet) from the top), the embedment depth can be determined.

The above equations are from "Effect of Depth of Embedment on Pole Stability", Wood Preserving News, Vol X, No. 11, November, 1932.

In order to use the above equation, good, average, and poor soils must be defined. The following is proposed as a description of good, average, and poor soils:

a. Good: Very dense, well graded sand and gravel, hard clay, dense, well graded, fine and coarse sand

b. Average: Firm clay, firm sand and gravel, compact sandy loam.

c. Poor: soft clay, poorly compacted sands (loose, coarse, or fine sand), wet clays and soft clayey silt

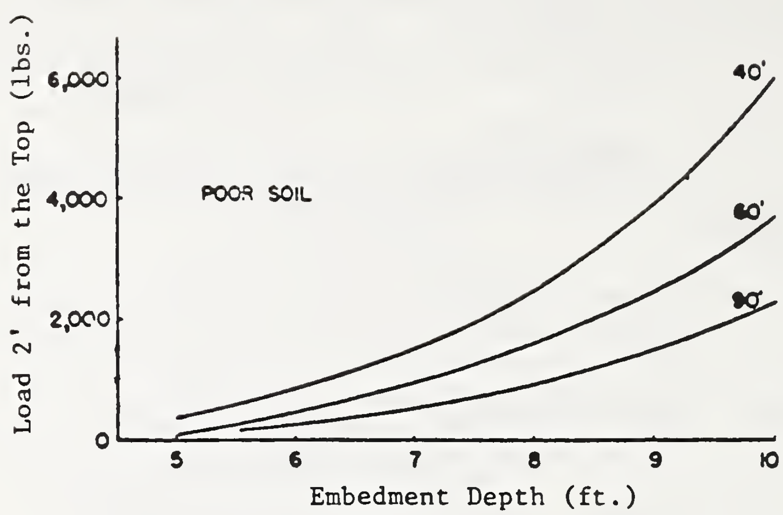


FIGURE 12-1: POOR SOIL

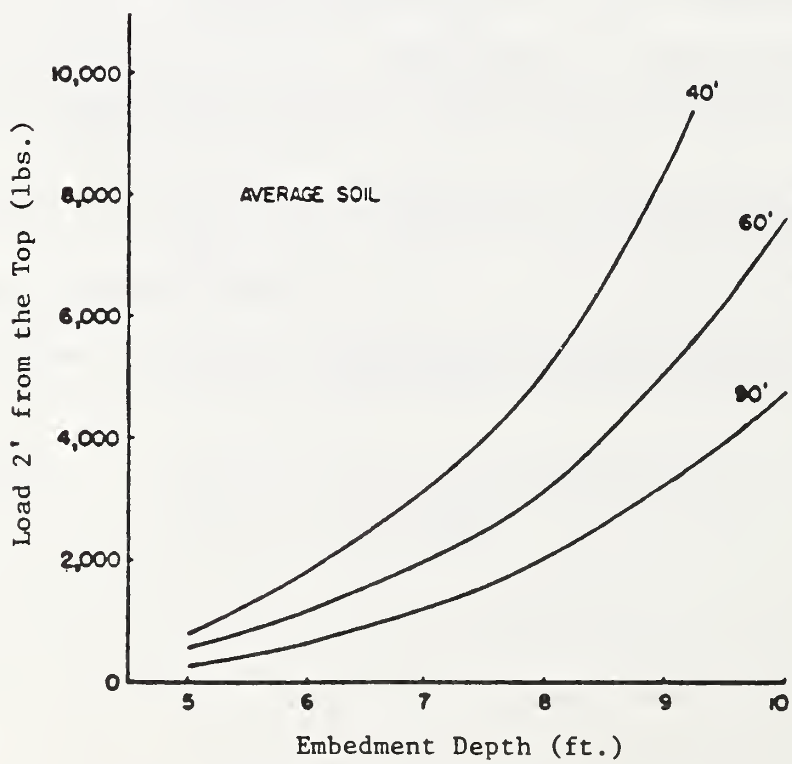


FIGURE 12-2: AVERAGE SOIL

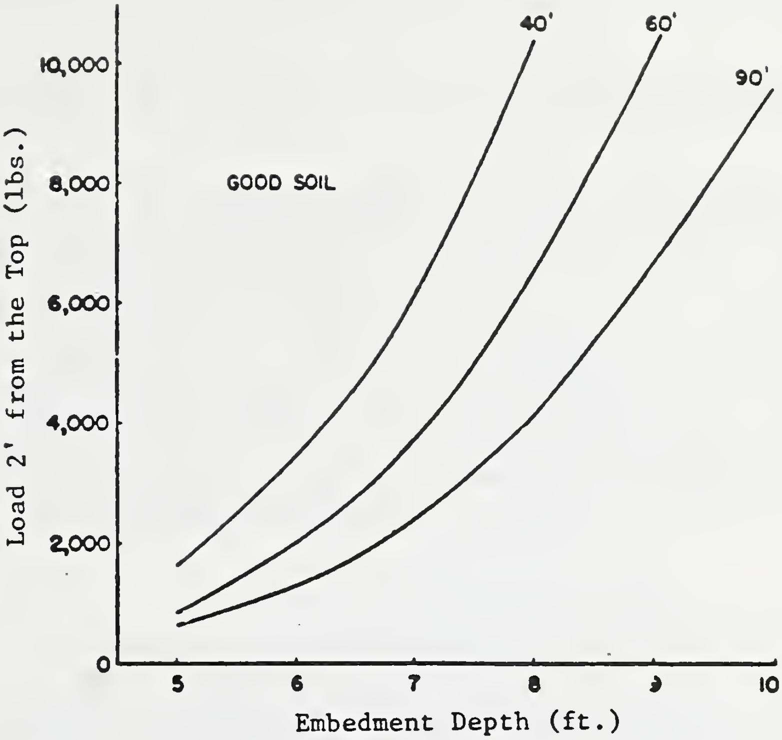


FIGURE 12-3: GOOD SOIL

12.3.2 If experience has indicated that single pole lines have had to be replumbed in an area, there are several methods which should be considered in order to reduce the frequency of replumbing lines. These are as follows:

a. Use a lower grade species of wood in order to increase embedment diameters. For instance, embedment diameters for Class 1 Western red cedar poles will be greater than embedment diameters for Douglas fir.

b. Use aggregate backfill.

c. Install a pole key with or without a pole toe of crushed stone, gravel, or concrete.

d. Embed one foot deeper.

12.3.3 Some general observations can be made when using equation 12-1:

a. The rule of thumb of "10 percent + .61 meters (2 ft.)" is adequate for most wood structures in good soil.

b. For Class 2 and larger class poles and poles of heights less than 18.3 meters (60 ft.), pole embedment depths should be increased .61 meters (2 ft.) or more in poor soil (single pole structures).

c. For Class 2 and larger class poles and poles of heights less than 12.2 meters (40 ft.), pole embedment depths should be increased .3 to .6 meters (1-2 ft.) in average soil (single pole structures).

d. For H-frame wood structures, "10 percent + .61 meters (2 ft.)" seems to be adequate for lateral strengths. Embedment depths are often controlled by pullout resistance.

12.4 <u>Bearing Capacity</u>: In order to prevent a guyed pole from continually sinking into the ground due to induced vertical loads, the pole butt should provide sufficient bearing surface area. If little soil information is available, local building codes might be helpful in determining allowable bearing capacities. These values usually are conservative and reflect the hazards associated with differential deflection in a building. Fortunately, wood transmission lines can sustain deflections on the order of several times that of buildings without detrimentally affecting their performance. As such, the bearing capacity of guyed wood poles is not as critical as that for buildings. Good engineering judgment and local experience should be used in determining if bearing capacities of a certain soil will be exceeded by guyed poles.

TABLE 12-2
PRESUMPTIVE ALLOWABLE BEARING CAPACITIES, kPa (ksf)

Soil Description	Chicago 1966		Atlanta 1950		Uniform Bldg. Code 1964	
Clay, very soft	23.9	(.5)	95.8	(2.0)	71.8	(1.5)
Clay, soft	71.8	(1.5)	95.8	(2.0)	71.8	(1.5)
Clay, ordinary	119.7	(2.5)	191.5	(4.0)		
Clay, medium stiff	167.6	(3.5)			119.7	(2.5)
Clay, stiff	215.5	(4.5)	191.5	(4.0)		
Clay, hard	287.3	(6.0)			383.0	(8.0)
Sand, compact and clean	239.4	(5.0)				
Sand, compact and silty	143.6	(3.0)				
Inorganic silt, compact	119.7	(2.5)				
Sand, loose and fine					71.8	(1.5)
Sand, loose and coarse, or sand-gravel mixture, or compact and fine					119.7	(2.5)
Gravel, loose, and compact coarse sand			383.0	(8.0)	383.0	(8.0)
Sand-gravel, compact			574.6	(12.0)	383.0	(8.0)
Hardpan, cemented sand, cemented gravel	574.6	(12.0)	957.6	(20.0)		
Soft rock						
Sedimentary layered rock (hard shale, sandstone, siltstone)			1,436.4	(30.0)		
Bedrock	9,580.0	(200.0)	9,576.0	(200.0)		

TABLE 12-3
SUGGESTED RANGES OF PRESUMPTIVE
ULTIMATE BEARING CAPACITIES, kPa (psf)*

Specific Description (Dry)		
Soft clay	95.8 - 287.3	(2000 - 6000)
Ordinary clay	287.3 - 430.9	(6000 - 9000)
Stiff clay	574.6	(12000)
Hard clay	718.1	(15000)
Loose sand	213.4	(4500)
Compact silty sand	430.9	(9000)
Compact clean sand	718.1	(15000)
Hardpan	1915.2	(40000)
General Description (Dry)		
Poor soil	143.6 - 191.5	(1500 - 4000)
Average soil	239.4 - 430.9	(5000 - 9000)
Good soil	574.6 - 861.7	(12000 - 18000)

*NOTE: Ultimate values are based on three times allowable. The values in the table are considered approximate. For more accurate bearing capacity values, bearing capacity equations should be used.

12.5 Uplift: When H-frame structures with X-braces are subject to overturning forces, one leg will be in compression and one leg in tension. The skin friction which the engineer assumes in design should be based on his experience, experience of nearby lines, and the results of the field survey. The following may be appropriate for average soil:

a. If the soil is wet or subject to frequent wettings, an ultimate skin friction not greater than 4.8 kPa (100 psf) should probably be assumed.

b. If native soil is used as backfill, an ultimate skin friction between 4.8 and 23.9 kPa (100 and 500 psf) should be assumed, provided the soil is not subject to frequent wettings.

c. If an aggregate backfill is used, an ultimate skin friction between 12.0 and 47.9 kPa (250 and 1000 psf) may be possible.

d. Pole "bearing" shoes increase uplift capacity of a dry hole with natural backfill on the order of 2 to 2.5 times. The use of aggregate backfill with bearing shoes is usually not necessary provided the native backfill material is of relatively good material.

e. In many cases, double cross-braced H-frame structures may require uplift shoes.

12.6 Construction - Backfill: Lateral and uplift resistance of wood poles will depend not only on type of soil, moisture content of the soil, depth of setting, but also on how well the backfill has been tamped.

All water should be removed before backfilling. If native backfill material is to be used, it should be free of grass, weeds, and other organic materials. If the dirt removed from the hole is too wet or has frozen, dry, unfrozen material should be obtained for the backfill. Where the earth removed from the hole is unsuitable as backfill, special backfill should be specified by the engineer. Drawing TM-101 suggests a gradation of aggregate to be used as backfill material.

When backfilling, the soil should be placed and compacted in shallow layers. Each layer should be compacted until the tamp makes a solid sound as the earth is struck. Power tamping is preferred using two power tampers and one shoveler. The importance of proper compaction of the backfill cannot be overemphasized. Insufficient tamping is a common source of trouble and has been the cause of some failures.

13. STRUCTURES

13.1 Economic Study: During the preliminary planning stages of lines above 161 kV, studies should be made which evaluate the economics of different types of structures as related to conductor size. In most instances, lines of voltages 230 kV and below, wood structures have historically been the economical choice. In some instances, other types of material have been used because of environmental or meteorological constraints. However, for voltages 345 kV and above, it may be difficult to obtain long span construction utilizing wood, due to height or strength reasons.

The preliminary cost estimates are usually based on level ground spans. For EHV lines and many of the higher voltage lines, the economic study should consider material costs, cost of foundations and erection, different structure heights, hardware costs, and right-of-way costs. The estimates are intended to give the borrower an idea as to relative rankings of various structure types and configurations such as steel lattice, steel pole, and wood H-frame or single pole. However, in the decision-making process, the manager may want to consider in his evaluation such intangibles as importance of the line to the power system, appearance, material availability, and susceptibility to environmental attack. In some areas, state or local constraints may ignore economics and specify the type of structure to be used.

In most instances, for lines 230 kV and below where wood has proven to be the structural material of choice, the economic study should help to determine structure configuration, base pole class and height.

Factors which limit wood structure spans include:

a. Strength: Horizontal spans limited by crossbrace, poles, etc.; vertical span limited by crossarms, structure strength; spans limited by pullout resistance for H-frame structures.

b. Conductor Separation: Conductor separation is intended to provide adequate space for workmen on poles, prevention of contacts and flashovers between conductors.

c. Clearances-to-Ground: Spans are directly related to height of structures.

d. Insulator Swing - The ratio of horizontal to vertical span will be limited by insulator swing and clearance to structure.

For practical purposes, the clearance-to-ground and structure strength is used to determine the level ground span to be used in an economic study. One means of determining the level ground span (points A and B) is by developing a graph as shown in Figure 13-1.

Structure cost per mile can then be related to pole height and class of poles as shown in Figure 13-2. In order to keep the cost down for wood transmission lines, the line should be based on one tangent structure type and one class pole for the majority of the line. For H-frame structures, the engineer should consider double crossbraces, as well as single crossbraces.

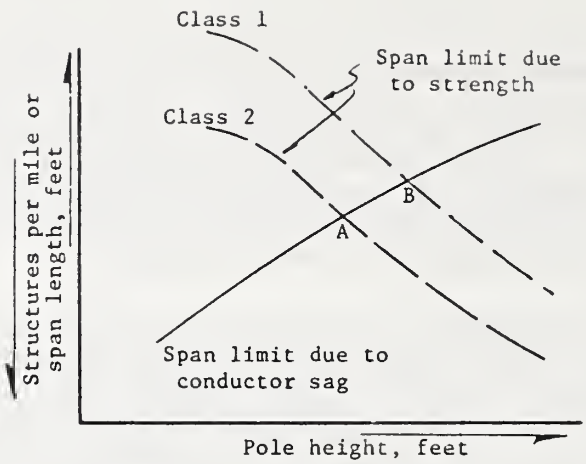


FIGURE 13-1: SELECTION OF LEVEL GROUND SPAN

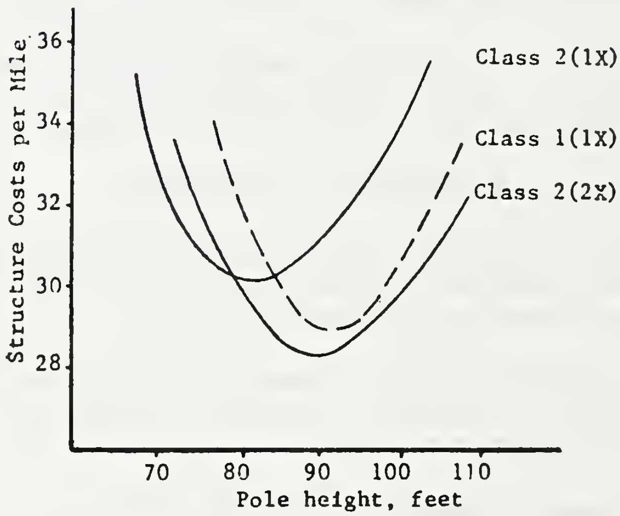


FIGURE 13-2: STRUCTURE COST PER MILE RELATED TO POLE HEIGHT

13.2 General Design Considerations

13.2.1 Stress Limitations: The structural stress limitations set forth in Table 13-1 are recommended for transmission lines using REA standard wood pole construction. These values assume that the wood has not deteriorated due to decay occurring in the manufacturing process.

TABLE 13-1

DESIGNATED STRESSES FOR POLES

Kind of Wood	Modulus of Elasticity x 1000 kPa	(psi)	Designated Ultimate Bending Stress (M.O.R.) kPa	(psi)
Western larch	11,800	(1710)	57,900	(8400)
Southern yellow pine	12,400	(1800)	55,200	(8000)
Douglas fir	13,200	(1920)	55,200	(8000)
Lodgepole pine	9,200	(1340)	45,500	(6600)
Jack pine	8,400	(1220)	45,500	(6600)
Red (Norway) pine	12,400	(1800)	45,500	(6600)
Ponderosa pine	8,700	(1260)	41,400	(6000)
Western red cedar	7,700	(1120)	41,400	(6000)
Northern white cedar	5,500	(800)	27,600	(4000)

Two types of woods may be used for crossarms - Douglas fir and Southern yellow pine. Southern yellow pine has four species which are long leaf (most popular species), loblolly, shortleaf, and slash. The coast type Douglas fir is the only type which should be used when specifying Douglas fir. Table 13-2 gives strength properties to be used in crossarm design.

TABLE 13-2

DESIGNATED STRESSES FOR CROSSARMS

Kind of Wood	Modulus of Elasticity x 1000 kPa	(psi)	Designated Ultimate Bending Stress (M.O.R.) kPa	(psi)	End Grain Max. Crushing Strength kPa	(psi)	Across Grain Stress kPa	(psi)	Shear Parallel to Grain kPa	(psi)
Douglas fir	13,200	(1920)	51,000	(7400)	51,200	(7420)	6,300	(910)	7,900	(1140)
Southern yellow pine (all species)	12,400	(1800)	51,000	(7400)	48,700	(7070)	6,900	(1000)	9,000	(1310)

13.2.2 <u>Preservative Treatment</u>: The decay of poles results from fungi and other low forms of plant life which attack untreated poles or poles with insufficient preservative. Damage by insect attack (termites, ants, and wood borers) is usually associated with decay. When the preservative retention is low, the wood cannot resist the attack by fungi and insects. There are two general classes of preservative treatment, oil-borne (creosote, and penta and copper naphthenate in petroleum) and waterborne (arsenates of copper).

Creosote oil was the predominant preservative for poles on rural systems until about 1947. Post-war shortages prompted the introduction of pentachlorophenol (penta) and copper naphthenate dissolved in the fuel oils, and other preservatives.

The second general class of preservative is the waterborne arsenates of copper (CCA and ACZA). These poles will be green in appearance. These preservatives were developed before World War II and have proven very effective as wood preservatives around the world. For species and amounts of treatment, refer to REA Specification for Wood Poles, Stubs, and Anchor Logs.

13.3 Single Pole Structures: Single pole wood structures are mainly limited in use to 115 kV and below. The six primary standard single pole structures utilized by REA borrowers are designated as:

TP - pin or post insulators
TPD - pin or post insulators, double circuit
TS - suspension insulators, crossarm construction
TSD - suspension insulators, crossarms, double circuit
TSZ - suspension insulators, "wishbone" arm construction
TU - suspension insulators, steel upswept arm construction

13.4 Maximum Horizontal Span Limits of Single Pole Structures: The following conditions should be taken into account when determining horizontal spans as limited by pole strength for tangent structures:

a. Wind on the conductors and OHGW is the primary load. Seventy five to ninety percent of the horizontal span will be determined by this load.

b. Wind on the structure will affect the horizontal span by 5 to 15 percent.

c. Unbalanced vertical load will increase ground-line moments. For single circuit structures, one phase is usually left unbalanced. The vertical load due to the conductor will induce moments at the groundline, and as such will affect horizontal span lengths by 2 to 10 percent. The engineer should determine if this is a significant load to incorporate into the design.

As a transverse load is applied to a structure, the structure will deflect. This deflection will offset the vertical load an additional amount "δ" causing an additional moment of the vertical weight times this deflection. This additional moment due to deflection is a secondary effect and sometimes is taken into account in wood pole transmission line designs. The high overload factor of four for heavy, medium, and light district loadings is intended to keep the design simple for low height structures and in line with known strength, foundation response, and loading conditions. For tall single pole structures with large conductors and significant transverse loading, the p-δ moments may have an impact on span calculations. An approximate method for taking into account the p-δ moments is given in section 13.4.2. Many designers routinely include p-δ moments in their calculations for horizontal span limitations.

Depending on the taper of the pole, the maximum stress may theoretically occur above the ground level. The general rule of thumb is that if the diameter at ground level is greater than one and a half times the diameter where the net pull is applied, the maximum stress occurs above the ground level. Even if the point of maximum stress occurs above the groundline, one can assume that

spans are based on groundline moments from a practical standpoint for REA Grade B construction. Spans over river, road, or line crossings could be limited to 75 percent of the calculated spans based on groundline moments.

The strength of the crossarm must be checked to determine its ability to withstand all expected vertical and longitudinal loads. The NESC requires crossarms to be capable of supporting a lineman and his equipment at the outermost extremity, in addition to the weight of iced conductors and insulators. When determining bending stress in crossarms, moments are taken about the through bolt, without considering the strength of the brace. The vertical force is determined by the vertical span under those conditions which yield the maximum vertical weight. The strength of two crossarms will be twice the strength of one crossarm. When considering the strength of the crossarm to withstand longitudinal loadings, reduction in the moment capacity due to bolt holes should be taken into account.

13.4.1 The general equation for determining the maximum horizontal span of a single pole structure is as follows:

$$HS = \frac{M_A - (OCF)(M_{wp})}{(OCF)(p_t)(h_1) + (OCF)(w_c)(s_t)} \qquad \text{Eq. 13-1}$$

where:

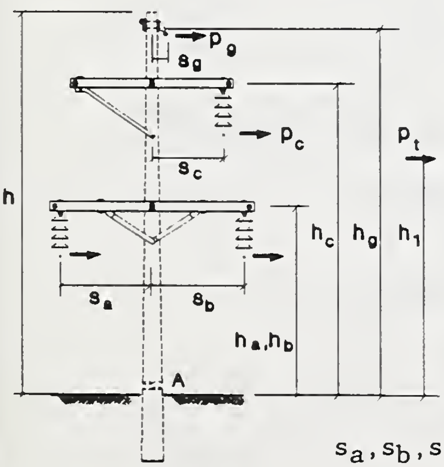
M_A = F_bS, the ultimate groundline moment capacity of the pole, N-m (ft-lbs).

F_b = the designated ultimate bending stress (M.O.R.).

S = the section modulus of the pole at the groundline (see Appendix G). For moment capacities of poles at the groundlines, see Appendix F.

$$M_{wp} = \frac{(F)(2d_t + d_a)(h)^2}{6}, \text{ moment due to wind on the pole, N-m, (ft-lbs).} \qquad \text{Eq. 13-2}$$

F = wind pressure in Pa (psf).



HS = horizontal span, meters (feet)

OCF = overload capacity factor

d_t = diameter of pole at top in meters (ft.).

d_a = diameter of pole at groundline in meters (feet).

h = height of pole above groundline meters (feet). For moments at the groundline due to wind on pole, see Appendix F.

h_1 = moment arm of p_t; in the example,

$$h_1 = \frac{(h_a)(p_c)+(h_b)(p_c)+(h_c)(p_c)+(h_g)(p_g)}{p_t} \qquad \text{Eq. 13-3}$$

p_t = sum of transverse unit wire loads N/m, (lbs/ft); in example, $p_t = 3\ p_c + p_g$

w_c = weight of conductor per unit length, N/M (lbs/ft)

s_t = $s_a + s_b + s_c$

s_a, s_b, s_c, s_g = horizontal distance from center of pole to wire (positive value on one side of the pole, negative on the other)

FIGURE 13-3 TS TYPE STRUCTURE

13.4.2 The general equation for determining the maximum horizontal span of a single pole structure taking into account the additional moment due to deflection is given below:

$$M_A = M_g = (OCF)M_{wp} + (OCF)M_{wc} + (OCF)M_{vo} + (OCF)M_{p-\delta} \qquad \text{Eq. 13-1a}$$

There are other ways to estimate the load carrying capacity of a pole considering the additional moment due to deflection. The above equations and subsequent equations are approximate ways to calculate the maximum horizontal spans considering secondary effects.

Because $M_{p-\delta}$ is a function of the vertical span, the engineer should make an assumption as to the relationship of the vertical and horizontal span. In the equations which follow, the relationship used is: VS = 1.25HS. Refer to Figure 13-3 and Equation 13-1a when considering the following equations.

a. M_{wp} = groundline moment due to wind on the pole

$$M_{wp} = \frac{F(2d_t + d_a)(h)^2}{6} \qquad \text{Eq. 13-2}$$

b. M_{wc} = groundline moment due to wind on the wires

$$M_{wc} = p_t(h_1)HS \qquad \text{Eq. 13-2a}$$

c. M_{vo} = groundline moment due to unbalanced vertical load

$$M_{vo} = 1.25HS(w_c s_t + w_g s_g) + W_i s_t$$

where:

w_g = weight of overhead groundwire per unit length, N/m (lbs./ft.)
W_i = weight of insulators, N (lbs)

d. $M_{p-\delta}$ = groundline moment due to pole deflection

$$M_{p-\delta} = 1.25HS(w_t)\delta_{imp}$$

where:

w_t = total weight per unit length of all wires N/m, (lbs./ft.)

$$\delta_{imp} = \left(\frac{6.78(p_t)(HS)(h_c)^3}{E(d_a)^3(d_1)}\right)\delta_{mag} \qquad \text{(Metric)} \qquad \text{Eq. 13-3a}$$

$$\delta_{imp} = \left(\frac{6.78(p_t)(HS)(h_c)^3}{E(d_a)^3(d_1)(144)}\right)\delta_{mag} \qquad \text{(English)} \qquad \text{Eq. 13-3b}$$

δ_{imp} = improved estimate of deflection of the structure, m (ft.)

E =	modulus of elasticity	Pa (psi)
d_a =	diameter of pole at "A" groundline	m (ft.)
d_1 =	diameter of pole at height "h_1"	m (ft.)
δ_{mag} =	deflection magnifier (assume 1.15 initially)	unitless

e. After substitutions have been made from a,b,c, and d above, Eq. 13-1a can be reduced to a quadratic equation of the form below and solved for the horizontal span (see example 13.5.2):

$$a(HS)^2 + b(HS) + c = 0$$

$$HS = \frac{-b \pm \sqrt{b^2-4ac}}{2a} \qquad \text{Eq. 13-5a}$$

f. Once "HS" has been calculated, check the assumption of $\delta_{mag} = 1.15$:

$$\delta_{mag} = \frac{1}{1-\frac{1.25HS(W_t)}{P_{cr}}}$$ (See Chapter 14 for calculations of P_{cr})

13.5 <u>Example of maximum horizontal spans</u>: Determine the maximum horizontal spans for the TSS-1 structure (69 kV). Terrain is predominantly level, flat, and open. (Assume "s_g" is negligible.)

a. <u>Given</u>:

NESC heavy loading
Extreme wind - 766 Pa (16 psf)

Pole: Western red cedar, 60'-1
Cond: 266.8 kcmil, 26/7 ACSR (Partridge)
Ground wire: 3/8" H.S.S.

	Heavy	High Wind
b. Conductor loads: N/m (lbs/ft)		
Transverse	7.987 (.5473)	12.492(.8560)
Vertical	15.726(1.0776)	5.360(.3673)
Ground wire loads: N/m (lbs/ft)		
Transverse	6.6250(.4533)	7.005(.4800)
Vertical	11.790 (.8079)	3.984(.2730)

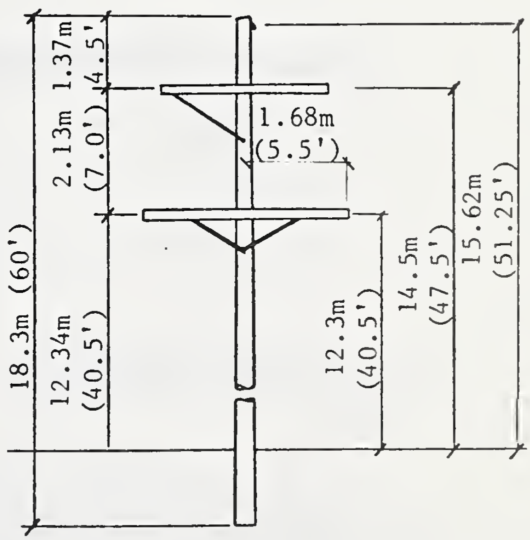


FIGURE 13-4: TSS-1 STRUCTURE

c. F_b(pole) = 41,400 kPa (6000 psi)

F_b(crossarm) = 51,000 kPa (7400 psi)

S(groundline) = 7.50×10^{-3} m^3 (458 in^3)

S(crossarm) = 3.72×10^{-4} m^3 (22.7 in^3)

Wt. of insulator = 222.4 N (50 lbs.)

Dia. (top) = .218 m (8.59 in.)

Dia. (groundline) = .425 m (16.72 in.)

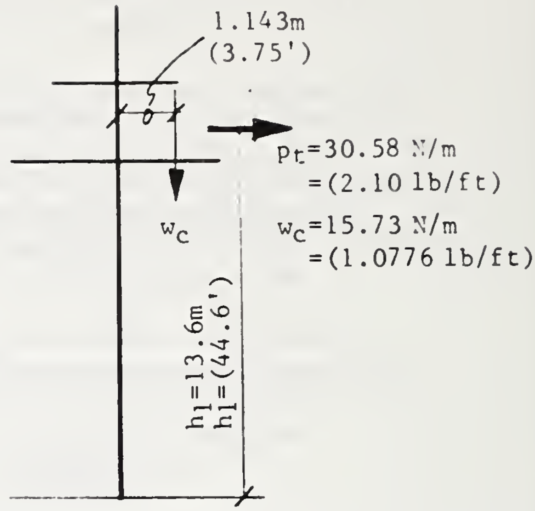


FIGURE 13-5: APPLICATION OF FORCES (HEAVY LOADING)

13.5.1 <u>Solution for the horizontal span (ignoring P-δ moments)</u>:

a. Horizontal Span Heavy Loading:

Metric

$$HS = \frac{M_g - 4M_{wp}}{4(p_t)(h_1) + 4(w_c)(s)}$$

a. $M_g = F_b(S)$

$M_g = (41,000 \times 10^3)(7.5 \times 10^{-3})$
$= 310,500$ N-m

b. $M_{wp} = (191.5)\left(\frac{2(.218) + .425}{6}\right)(15.85)^2$

c. $p_t = 3(7.987) + 6.615$
$= 30.58$ N/m

$h_1 = 13.6$ m

$w_c = 15.72$ N/m

$s = 1.143$ m

$$HS = \frac{310,400 - 4(6900)}{4(30.58)(13.6) + 4(15.72)(1.143)}$$

= 163 m

English

$$HS = \frac{M_g - 4M_{wp}}{4(p_t)(h_1) + 4(w_c)(s)}$$

a. $M_g = F_b(S)$

$M_g = \frac{6000(458)}{12}$

= 229,000 ft-lbs.
(or see Appendix F)

b. $M_{wp} = (4)\left(\frac{(8.59) + 16.72}{72}\right)(52)^2$

= 5100 ft-lbs.
(or see Appendix F)

c. $p_t = 3(.5473) + .4533$
$= 2.10$ lbs/ft.

$h_1 = 44.6$ ft.

$w_c = 1.0776$ lbs/ft.

$s = 3.75$ ft.

$$HS = \frac{229,000 - 4(5100)}{4(2.10)(44.6) + 4(1.0776)(3.75)}$$

= 534 ft.

b. Check High Winds: The horizontal span limitation from high winds is 299 m (976 ft.) based on an overload factor of 1.5 on the wind and 1.0 on the weight load. This case is not limiting.

13.5.2 <u>Solution for Maximum Horizontal Span Considering P-δ moments:</u>

a. $$M_{wp} = \frac{4[(2)(8.59 + 16.72)](52)^2}{6(12)}$$
$= 5{,}100$ ft/lbs.

b. $M_{wc} = (2)(.5473)(40.5)HS + (.5473)(47.5)HS + (.4533)(5125)HS$
$= 93.5HS$

c. $M_{vo} = [(3)(1.0776) + (.8079)]\ HS(1.25)$
$= 4.04HS$

d. $M_{p\delta} = (1.25)(HS)(4.041)\delta imp$

$$\delta_{imp} = \frac{6.78(2.095)(HS)(44.6)^3\ (144)}{(1.12E06)(16.72)^3\ (9.74)}$$

$\delta_{imp} = .003558(1.15)HS$
$\delta_{imp} = .0041HS$

$M_{p\delta} = (4.041)(1.25)(HS)(.0041)(HS)$
$= .0207(HS)^2$

e. $M_g = (OCF)(M_{wp} + M_{wc} + M_{vo} + M_{p\delta})$
$= 4(5{,}100 + 93.5\ HS + 4.48HS + .0207HS^2)$

f. $a(HS)^2 + b(HS) + c = 0$
$.0828(HS)^2 + 391.1(HS) + 20{,}400 = 229{,}000$

$$HS = \frac{-391.1 + \sqrt{391.1^2 - 4(.0929)(-209{,}000)}}{2(.0828)}$$

HS = 484 feet

g. Once the HS has been calculated, the assumption of 1.15 as the magnifier should be checked.

$$\delta mag = \frac{1}{1 - \frac{(W_t)1.25\ HS}{P_{cr}}} \overset{?}{=} 1.15$$

$$\delta mag = \frac{1}{1 - \frac{(4.0407)(1.25)HS}{17.900}}$$
$= 1.1563$ O.K.

13.5.3 <u>Lateral Stability</u>: The Equivalent load 2 feet from the top is approximately 4400 lbs. From Figure 13-2 average soil, the embedment depth for a 4400 lb. load 2 feet from the top is between 8 and 8.5 feet. Lines nearby have performed well with the standard embedment depths. Engineering judgment dictates that an 8 foot embedment depth for the 60 foot pole will be sufficient.

13.6 Maximum Vertical Span of Single Pole Structures:

13.6.1 To determine the vertical span, the moment capacity of the arm at the pole is calculated. The vertical span for TP and TS type structures follows:

$$VS = \frac{M_a - (OCF)(W_i)(s_c)}{(OCF)(w_c)(s_c)} \qquad \text{Eq. 13-4}$$

where:
$M_a = F_b S$, moment capacity of the arm, N-m (ft-lbs).
where:
F_b = the designated bending stress.
S = the section modulus of the arm (see Appendix G.)
w_c = weight of the conductor per unit length, N/m (lbs/ft).
s_c = moment arm, meters (feet).
W_i = insulator weight, N (lbs.).
VS = vertical span, meters (feet).

13.6.2 Example of Vertical Span Calculations for TS Type Structure (Heavy Loading): w_c = 1.0776 lbs./ft., see Figure 13.4

Metric

$$VS = \frac{M_a - (OCF)(W_i)(S)}{(OCF)(w_c)(s)}$$

a. $M_a = F_b S$
$M_a = (51{,}000 \times 10^3)(3.72 \times 10^{-4})$
$= 18{,}900$ N-m

b. $W_i = 102.3$ N

$$VS = \frac{18{,}900 - (4.0)(222.4)(1.68)}{4(15.726)(1.68)}$$
$= 165$ m

English

$$VS = \frac{M_a - (OCF)(W_i)(s)}{(OCF)(w_c)(s)}$$

a. $M_a = F_b S$
$M_a = 7400(22.7)/12$
$= 14{,}000$ ft-lbs.
(see Appendix G)

b. $W_i = 50$ lbs.

$$VS = \frac{14{,}000 - (4.0)(50)(5.5)}{(4(1.0776)(5.5)}$$
$= 544$ ft.

The strength of the arm should be checked for maximum iced conductors with a lineman on the end of the arm.

13.6.3 The TSZ structure, a wishbone-type crossarm assembly, is intended for use on transmission lines where conductor jumping due to ice unloading and/or conductor galloping are problems. The wishbone provides additional vertical and horizontal offset between phases in order to reduce the possibilities of phase-to-phase faulting due to the above conditions.

Since the crossarms of the wishbone are not horizontal, the vertical span is related to the horizontal span. The maximum vertical load (W_c) the TSZ-1 single crossarm assembly can withstand is 15,100 N (3,400 lbs.) at any conductor position. By calculating moments at point "A" on the assembly, horizontal and vertical spans are related (see example 2). Spans limited by pole strength are calculated in the same manner as the TP and TS structures.

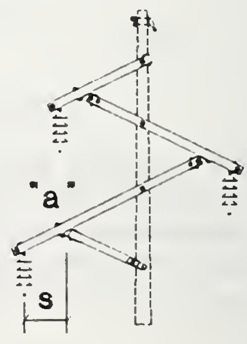
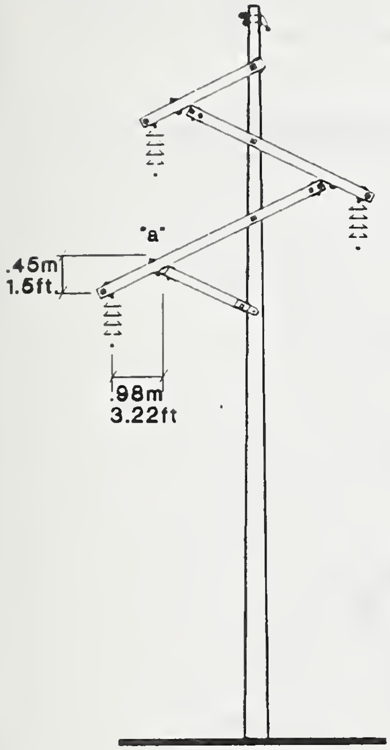


FIGURE 13-6: TSZ-1

13.6.4 Example of Span Calculations for Wishbone Structures: Determine the maximum horizontal and vertical spans for the crossarm assembly for the TSZ-1 structure (69 kV).



Given:

1. NESC heavy loading district

Extreme wind - 766 Pa (16 psf)

2. Pole: S.Y.P. (70-1)
Cond: 266.8 kcmil, 26/7 ACSR (Partridge)
Ground wire: 3/8" H.S.S.

3. Conductor loads (see example 1)

Solution

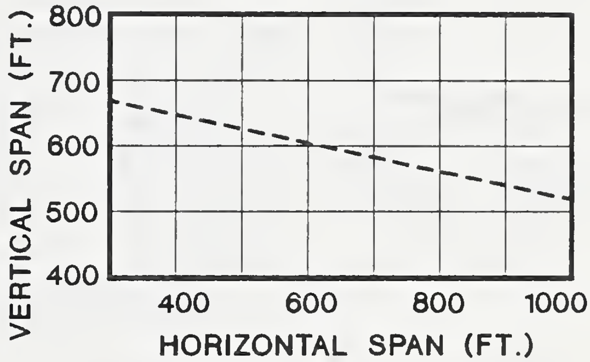


FIGURE 13-7: TSZ-1

FIGURE 13-8: HS vs VS FOR TSZ-1

Solution

a. Moment capacity of crossarm at A: $M_a = W_c(s)$

$$M_a = 15{,}100(.98) = 14{,}800 \text{ N-m}$$

$$M_a = 3{,}400(3.22) = 10{,}930 \text{ ft-lbs.}$$

b. Horizontal and vertical span: (relationship is obtained by summing moments about point A).

(Metric)

$$4(7.987)(.45)HS+4(15.726)(.98)VS+4(222.4)(.98) = 14{,}800 \text{ N-m}$$
$$29.1HS+123.3VS = 13{,}928 \text{ N-m}$$

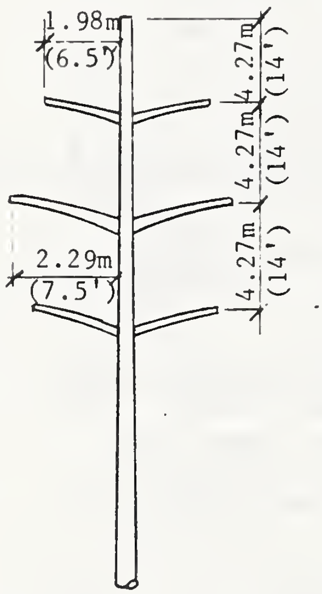
(English)

$$4(.5473)(1.5)HS+4(1.0776)(3.22)VS+4(50)(3.22) = 10{,}930 \text{ ft-lbs.}$$
$$6.57HS+27.7VS = 10{,}287 \text{ ft-lbs.}$$

c. For HS = VS, Span = 183 m (600 ft.). See Figure 13-8 for application chart.

13.6.5 TU-1 Structures: The TU-1 structures have steel upswept arms. Drawing TM-115 gives basic dimensions and other information concerning the steel upswept arms. All arms will carry a minimum 1000 pounds longitudinal load. Since the arms are upswept, vertical spans are related to horizontal spans and a graph can be made to related horizontal and vertical spans. Spans limited by pole strength are calculated in the same manner as the TP and TS structures.

13.6.6 Example of Span Calculations for Steel Davit Arm Construction: For the 138 kV structure shown, plot the horizontal versus vertical span for the crossarms. Terrain is rolling foothills.



Given:

1. NESC light loading district
Extreme wind - 622 Pa (13 psf)

2. Pole: Southern yellow pine
Cond: 447 kcmil, 26/7 ACSR (Hawk)
Ground wire: 3/8" H.S.S.

3. Conductor loads:

N/m (lbs/ft.)	Light	High Wind
Transverse	9.391 (.6435)	13.565 (.9295)
Vertical	9.588 (.6570)	9.588 (.6570)

4. Manufacturers catalog data for crossarms:

S	R	Rated Ult. (W_c) Vertical Load
2.29m(7.5')	.82m(2.7')	11,600 N(2600 lbs.)
1.98m(6.5')	.76m(2.5')	11,500 N(2580 lbs.)

5. Weight of insulators (W_i) = 454 N (102 lbs.)

FIGURE 13-9: DOUBLE CIRCUIT TU-1 STRUCTURE

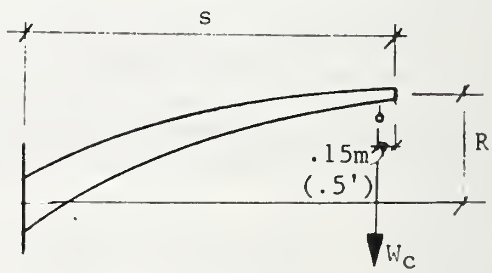


FIGURE 13-9a: DAVIT ARM

Solution

a. For the 2.29 m (7.5') davit arm:

(1) Moment capacity of arm at pole:

$$\begin{aligned} Ma &= Wc(s) \\ &= (11{,}600)(2.29-.15) \\ &= (11{,}600)(2.14) \\ &= 24{,}700 \text{ N-m} \end{aligned}$$

$$\begin{aligned} Ma &= Wc(s) \\ &= (2600)(7.5-.5) \\ &= (2600)(7.0) \\ &= 18{,}200 \text{ ft-lbs.} \end{aligned}$$

(2) Vertical and horizontal spans: (Metric and English)

$$4(9.391)(.82)HS+4(9.588)(2.14)VS+4(454)(2.14) = 24{,}700 \text{ N-m}$$
$$30.9HS+82.1VS = 20{,}810 \text{ N-m}$$

$$4(.6435)(2.7)HS+4(.6570)(7.0)VS+4(102)(7.0) = 18{,}200 \text{ ft-lbs.}$$
$$6.95HS+18.4VS = 15{,}340 \text{ ft-lbs.}$$

b. For the 1.98 m (6.5′) davit arm:

(1) Moment capacity of arm at pole:

$$Ma = Wc(s) = (11{,}500)(1.98-.15) = (11{,}500)(1.83) = 21{,}000 \text{ N-m}$$

$$Ma = Wc(s) = (2580)(6.5-.5) = (2580)(6.0) = 15{,}480 \text{ ft-lbs.}$$

(2) Vertical and horizontal spans: (Metric and English)

$$4(9.391)(.762)HS+4(9.588)(1.83)VS+4(454)(1.83) = 21{,}000 \text{ N-m}$$
$$28.6HS+70.2VS = 17{,}680 \text{ N-m}$$

$$4(.6435)(2.5)HS+4(.6570)(6.0)VS+4(102)(6.0) = 15{,}480 \text{ ft-lbs.}$$
$$6.44HS+15.77VS = 13{,}030 \text{ ft-lbs.}$$

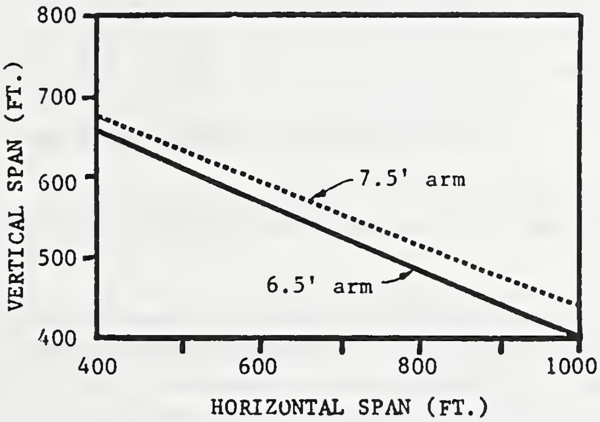


FIGURE 13-10: VS vs HS FOR TUS-1 STRUCTURE OF EXAMPLE 13-3

13.7 <u>H-Frame Structures</u>:

13.7.1 <u>General</u>: There are various techniques available for analysis of H-frame structures: (1) classical indeterminate structural analysis, (2) matrix methods of structural analysis, and (3) approximate methods.

Conventional indeterminate structural analysis and matrix methods of structural analysis, although more accurate, do not readily lend themselves to design of wood transmission lines. The approximate method of analysis is commonly used for several reasons:

- o Wood is a variable product. More accurate analysis techniques do not always mean assured safety. Approximate analysis techniques should be used as a minimum in design calculations. More sophisticated analysis techniques may be satisfactory provided engineering costs do not become inflated.

- o Classical indeterminate analysis methods are found to be too cumbersome.

- o Matrix methods of analysis require access to a computer, which is not always convenient.

- o Loadings cannot be predicted or determined with a high degree of accuracy. Overload factors are used to account for accuracy and importance of loads, as well as method of analysis, and material or construction variables.

13.7.2 In analyzing a statically indeterminate structure by approximate procedures, one assumption is made for each degree of indeterminacy. These assumptions are based on logical interpretations of how the structure will react to a given loading. For the H-frame with knee and V-braces, we can assume that the structure will behave as shown below:

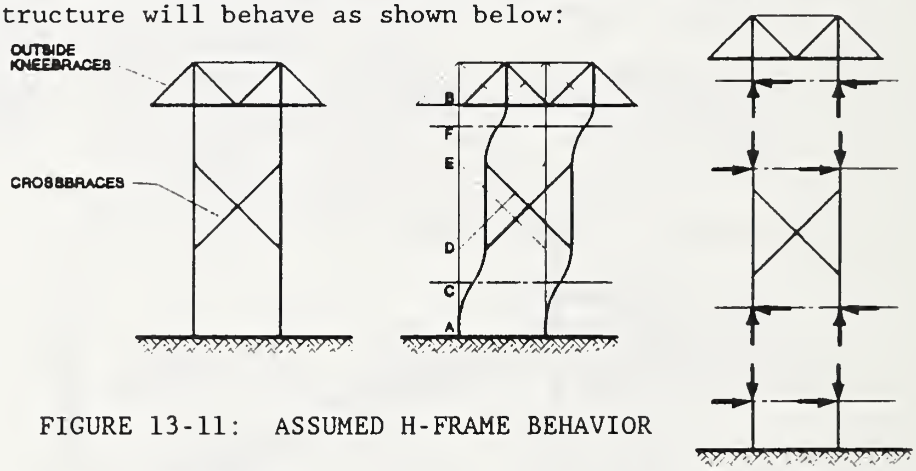


FIGURE 13-11: ASSUMED H-FRAME BEHAVIOR

At some point in the poles, there will be an inflection point (a point of zero moment). If the pole or column is uniform in cross section, it is common to assume that the inflection point is located midway between points of bracing, shown as a dotted line in Figure 13-11. However, since the pole is tapered, the following relationship may be used to determine the location of the inflection point (see Appendix H for application chart).

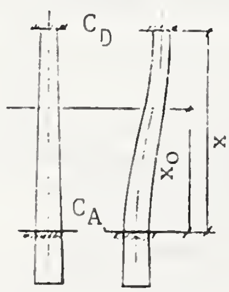


FIGURE 13-12: LOCATION OF POINT OF CONTRAFLEXURE

$$\frac{x_o}{x} = \frac{C_A(2C_A + C_D)}{2(C_A^2 + C_A C_D + C_D^2)} \qquad \text{Eq. 13-5}$$

where:
C_A = circumference at base
C_D = circumference at top

By applying the same reasoning, the inflection point can be located on the other column. Locating the inflection point on each column, and hence the point of zero moment, entails two assumptions for the frame. Since the frame is statically indeterminate to the third degree, a third assumption must be made. A common third assumption is that the shear in the columns is distributed equally at the inflection points. The shear in the columns is equal to the horizontal force on the structure above the level under consideration.

For a less rigid support, the inflection point moves toward the less rigid support. Two conclusions can be made:

- For a pole rotating in the ground, the inflection point "C" below the crossbraces, is lowered, thereby increasing the moment induced in the pole at the connection of the lower crossbrace. Since the amount of rotation of a base is difficult to determine, the usual design approach is to always assume a rigid base.

- For H-frames with outside kneebraces only, the point of inflection "F" above the crossbrace (shown in Figure 13-11) is higher than the point of inflection for four kneebraces; thereby increasing the moment in the pole at the upper crossbrace-pole connection. For the H-frame with outside kneebraces only, the designer will make one of two assumptions:

  (1) The kneebraces are ignored and no point of inflection exists between the crossbrace and the crossarm when determining induced moments in the poles. This is a conservative assumption and assumes that the purpose of outside braces is to increase vertical spans only.

  (2) The point of inflection occurs at the crossarm. This assumption will be used in the equations and examples which follow.

13.7.3 <u>Crossbraces</u>: The primary purpose of wood X-bracing for H-frame type structures is to increase horizontal spans by increasing structure strength. Additional benefits achieved by wood crossbracing include possible reduction of right-of-way costs by eliminating some guys and reduction of lateral earth pressures. For an efficient design, several calculations should be made in order to correctly locate the crossbrace.

The theoretical maximum tensile or compressive load which the wood crossbrace will be able to sustain will largely be dependent on the capacity of the wood brace to sustain a compressive load. Drawing TM-110, X-brace Assembly is to be used for the 115, 138, 161 kV, and 230 kv tangent structures. The crossbrace dimension is 3-3/8" x 4-3/8" for the 115 kV structure, 3-3/8" x 5-3/8" for 138 and 161 kV structures. The dimensions of this X-brace for the TH-230 structure are 3-5/8" x 7-1/2" (minimum).

The maximum compressive load which a wood X-brace is able to sustain is determined by:

$$P_{cr} = \frac{A(\pi^2)E}{\left(\frac{k\ell}{r}\right)^2} \qquad \text{Eq. 13-6}$$

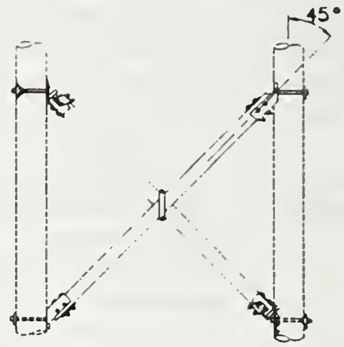


FIGURE 13-13:
CROSSBRACE

where:

Pcr = maximum compressive load, N (lbs.).
A = area, m^2 (in^2).
E = modulus of elasticity, pa (psi).
$k\ell$ = effective unbraced length, m (in.).
r = radius of gyration, m (in.), which will give you the maximum $\frac{k\ell}{r}$ ratio.

$k\ell$ and r must be compatible for the same axis.

For an assumed .305 m (1 ft.) diameter pole, the following theoretical values apply:

TABLE 13-3

Wood Dimensions	A Area (in^2)	r Least Rad. Gyr.	L Dist. C_L to C_L of Poles	.5L/.707 (Less 1' for Pole Dia.)	$\frac{k\ell}{r}$	P_{cr}, N (lbs.) (for E = 1.8 x 10^6)
TM-110						
3-3/8" x 4-3/8"	14.77	.9743"	12.5'	97.6"	100.2	116,100 (26,100)
3-3/8" x 5-3/8"	18.14	.9743"	15.5'	123.1	126.3	89,900 (20,200)
TM-110A						
3-5/8" x 7-1/2"	27.19	1.05	19.5	157"	149.5	96,100 (21,600)

The above calculations, though, do not reflect the capacity of the hardware. REA Specification 1728E-T7, REA Specifications for Double Armed and Braced Type Crossarm Assemblies (138 and 161 kV), and REA Specification 1728E-T8, REA Specifications for Double Armed and Braced Type Crossarm Assemblies (230 kV), require X-braces to withstand a tension or compression loading of 89,000 N (20,000 lbs.). This ultimate value correlates with the above theoretical ultimate loads. It is recommended that 89,000 N (20,000 lbs.) (ultimate) be used for design purposes, since this value assures one that the crossbrace will sustain the indicated load.

For the 115 kV structure (TH-1AA) it is recommended that 89,000 N (20,000 lbs.) be used as the ultimate load which the crossbrace is able to sustain. According to the list of materials, the hardware for the crossbrace is the same as that hardware used with 138 and 161 kV structures.

13.7.4 V-Braces: The primary purpose of two V-braces on the outside of the poles is to increase vertical spans. Two V-braces on the inside will increase horizontal spans. Four V-braces increase both horizontal and vertical spans. The various bracing arrangements and their designations for 161 kV structures are shown in Figure 13-14.

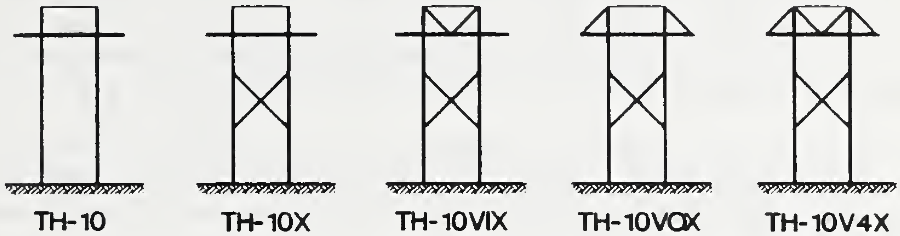


FIGURE 13-14: POLE TOP BRACING ARRANGEMENTS

REA Specification 1728E-T7 (138 and 161 kV double crossarm assemblies) has the following minimum strengths:

Maximum vertical load (at any conductor position

TH-10	35,600 N	(8,000 lbs.)
TH-10VO	62,300 N	(14,000 lbs.)
TH-10V4	62,300 N	(14,000 lbs.)

Maximum transverse conductor load (total

TH-10VO	66,750 N	(15,000 lbs.)
TH-10V4	66,750 N	(15,000 lbs.)

Maximum tension or compression in V-brace

89,000 N (20,000 lbs.)

REA Specification 1728-T8 (230 kV double crossarm assemblies) has the following minimum strengths:

Maximum vertical load (at any conductor position)

TH-230	44,500 N	(10,000 lbs.)

Maximum transverse conductor load (total)

TH-230	66,750 N	(15,000 lbs.)

Maximum tension or compression in V-brace

89,000 N (20,000 lbs.)

When determining maximum vertical and horizontal spans as limited by H-frame top assemblies, the above minimum strengths may be used as guidance.

13.8 <u>Structure Analysis of H-frames</u>: Pages 13-22 to 13-25 indicate equations for calculating forces in the various members of an H-frame structure. Structure 3 with two outside V-braces needs further explanation.

A structure with two outside V-braces has less rigidity above the crossbrace than a structure with four braces. The location of the point of contraflexure is difficult to determine. The equation given which calculates the moment (M_E) at the top of the crossbrace assumes that the point of contraflexure exists at the crossarm. However, when determining span limitations due to strength of the pole top assembly using Equation 13-7, a point of contraflexure is assumed between the top of the crossbrace and the crossarm.

As part of the structural analysis, span limitations due to strength of the pole top assembly should be considered and suggested methods follow. Appropriate overload capacity factors should be applied in the respective equations.

13.8.1 <u>Outside V-Braces</u>: As mentioned previously, two outside V-braces provide less rigidity than four braces. To determine maximum span limited by the V-braces, a point of contraflexure is assumed between the crossarm and the top of the crossbrace in accordance with Equation 13-5. The maximum vertical span is determined for the maximum horizontal span.

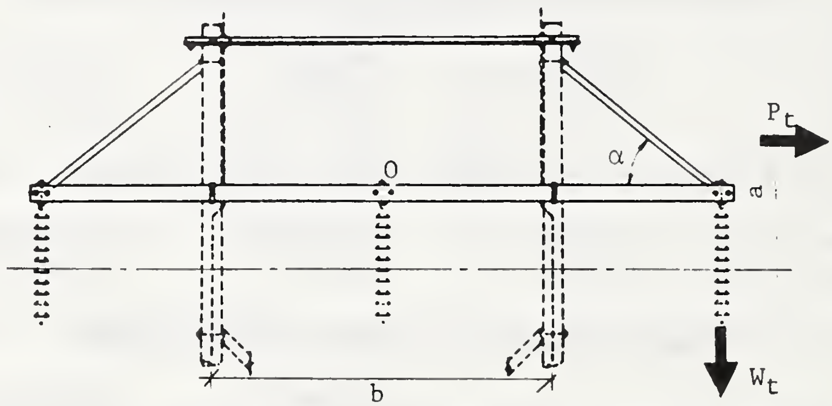


FIGURE 13-15: POLE TOP ASSEMBLY WITH TWO OUTSIDE BRACES

o Ultimate force in the brace:

$$\frac{W_t}{\sin\alpha} \pm \frac{P_t(a)}{(b)\sin\alpha} \leq 89{,}000 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. 13-7}$$

where:

W_t = total vertical load at the phase wire locations, in N (lbs.), $W_t = VS(w_c)+W_i$
P_t = total transverse load, in N (lbs.), $P_t = (HS)(3p_c+2p_g)$.
a = distance from the point of contraflexure to equivalent force, m (ft.).
b = distance between poles, m (ft.).

13.8.2 <u>Two Inside V-Braces</u>: Pole bending moment, uplift, and force in the X-brace may be calculated in the same manner as when four braces are used. Crossarm strength controls the maximum vertical span.

a. Force in the braces:

$$\frac{W_t}{2\sin\alpha} \pm \frac{P_t(a)}{(b)\sin\alpha} \leq 88{,}900 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. 13-8}$$

b. Crossarm bending moment:

$$M_o = \frac{W_t(b)}{2} \qquad \text{Eq. 13-9}$$

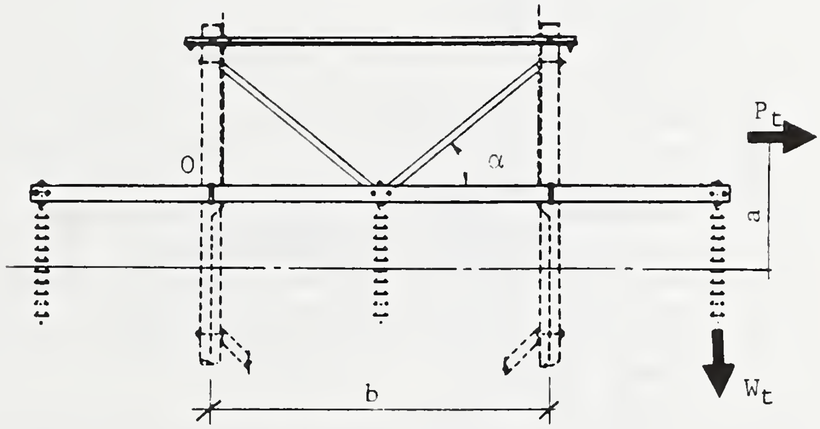


FIGURE 13-16: POLE TOP ASSEMBLY WITH INSIDE BRACES

13.8.3 <u>Four V-Braces</u>: The following equations can be used to determine the maximum vertical span as limited by the V-braces, given the maximum horizontal span:

a. Force in the outside braces:

$$\frac{W_t}{\sin\alpha} \leq 88{,}900 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. 13-10}$$

b. Force in the inside braces:

$$\frac{W_t}{2\sin\alpha} \pm \frac{P_t(a)}{(b)\sin\alpha} \leq 88{,}900 \text{ N } (20{,}000 \text{ lbs.}) \qquad \text{Eq. 13-8}$$

The equations for determining spans for different types of wood H-frame structures are given on pages 13-22 to 13-25. All units should be consistent. The following abbreviations apply:

D_e = embedment depth.
F = wind pressure on a cylindrical surface, Pa (psf).
F_s = presumptive skin friction value, Pa (psf).
HS = horizontal span, m (ft.).
M_a = moment capacity of crossarm.
M_n = moment capacity at the indicated location, "n", N-m (ft-lb.), includes moment reduction due to bolt hole, i.e., $M_N = M_{cap} - M_{bh}$.
OCF = overload capacity factor.
Q_u = ultimate bearing resistance of the soil, Pa (psf).
R_n = reaction at the indicated location,"n", N (lbs.).
SF = safety factor
U = dummy variable.
V = dummy variable.
V_n = induced axial force at the indicated location, "n", N (lbs.).
VS = vertical span, m (ft.).
W_c = weight of conductors (plus ice, if any), N (lbs.).
W_g = weight of OHGW (plus ice, if any), N (lbs.).
W_p = weight of pole, N (lbs.).
W_t = total weight equal to weight of conductors (plus ice, if any)-W_c, plus weight of insulators-W_i.
W_1 = total resistance due to skin function around the embedded portion of the pole, N, (lbs).
W_2 = total bearing resistance of the soil, N, (lbs).
X = dummy variable.
Y = dummy variable.
d_{avg} = average diameter of pole between groundline and butt, m (ft.).
d_{bt} = diameter of pole at butt, m (ft.).
d_n = diameter at location "n", m (ft.).
d_t = diameter of pole at top, m (ft.).
f_s = calculated skin friction value, Pa (psf).
h_n - length as indicated, m (ft.).
P_t = total horizontal force per unit length due to wind on the conductors and overhead ground wire, N/m (lbs/ft.).
s_n = distance as shown, m (ft.).
w_c = weight per unit length of the conductors (plus ice, if any), N/m (lbs/ft.).
w_g = weight per unit length of overhead ground wire (plus ice, if any), N/m (lbs/ft.).

STRUCTURE 1
(Figure 13-17)

$$HS_A = \left[M_A - \frac{(OCF)(F)(h)^2(2d_t+d_a)}{6}\right] / \left[\frac{(OCF)(p_t)(h_1)}{2}\right] \qquad \text{Eq. 13-11}$$

$$R_A = W_g + 3/2W_t + W_p \qquad \text{Eq. 13-12}$$

$$VS = \frac{M_a - (OCF)(W_i)(s)}{w_c(s)(OCF)} \qquad \text{Eq. 13-13}$$

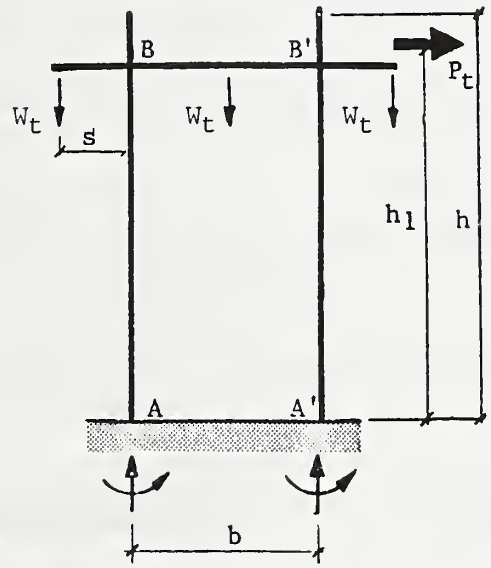


FIGURE 13-17

STRUCTURE 2
(Figure 13-18)

$$HS_B = \left[M_B - \frac{(OCF)(F)(y_1)^2(2d_t + d_b)}{6}\right] / (OCF)(p_g)(y_1) \qquad \text{Eq. 13-14a}$$

$$HS_E = \left[M_E - \frac{(OCF)(F)(y)^2(2d_t + d_e)}{6}\right] \Big/ \frac{(OCF)(p_t)(y_o)}{2} \qquad \text{Eq. 13-14b}$$

$$HS_D = \left[M_D - \frac{(OCF)(F)(h-x_o)(x_1)(d_t + d_c)}{2}\right] \Big/ \frac{(OCF)(p_t)(x_1)}{2} \qquad \text{Eq. 13-14c}$$

$$HS_A = \left[M_A - \frac{(OCF)(F)(h-x_o)(x_o)(d_t + d_c)}{2}\right] \Big/ \frac{(OCF)(p_t)(x_o)}{2} \qquad \text{Eq. 13-14d}$$

<u>For crossbrace</u>:

$$HS_x = \left[125{,}800(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / (OCF)(p_t)(h_2) \qquad \text{(Metric) Eq. 13-14e}$$

$$HS_x = \left[28{,}300(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / (OCF)(p_t)(h_2) \qquad \text{(English) Eq. 13-14f}$$

<u>For uplift</u>:

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) - X - Y \qquad \text{Eq. 13-14g}$$

<u>For bearing</u>:

$$HS(p_t)(h_2) + VS(w_g)(b) + 1.5VS(w_c)(b) = W_2(b) - W_p(b) + X - Y + W_1(b) \qquad \text{Eq. 13-14h}$$

where:

$W_1 = F_s(D_e)(d_{avg})\pi/S.F.$

$W_2 = (\pi d_{bt}^2/4)(Q_u)/S.F.$

$X = (F)(h-x_o)(d_t+d_c)(x_o)$

$Y = 2(F)(h)^2(2d_t+d_a)/6$

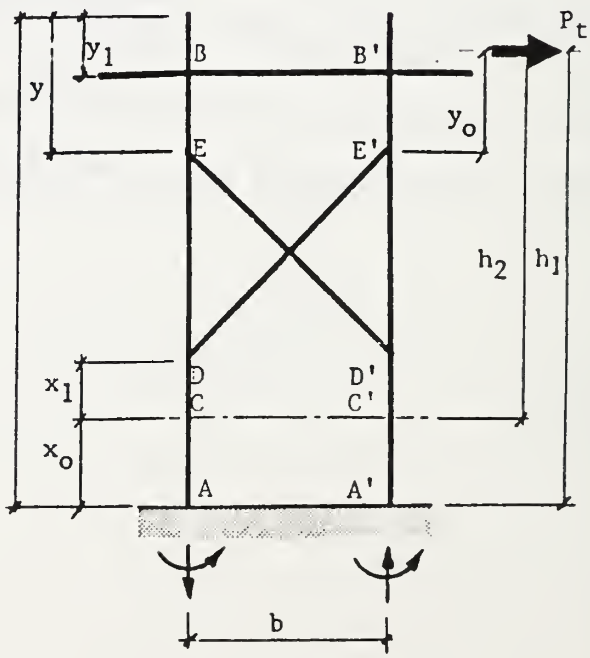


FIGURE 13-18

STRUCTURE 3
(Figure 13-19)

$$HS_E = \left[M_E - \frac{(OCF)(F)(y_1)(z)(d_t + d_b)}{2}\right] / \left[\frac{(OCF)(p_t)(z)}{2}\right] \quad \text{Eq. 13-15}$$

HS_D, HS_A = same as structure #2.

For crossbrace, uplift, and bearing: same as structure #2.

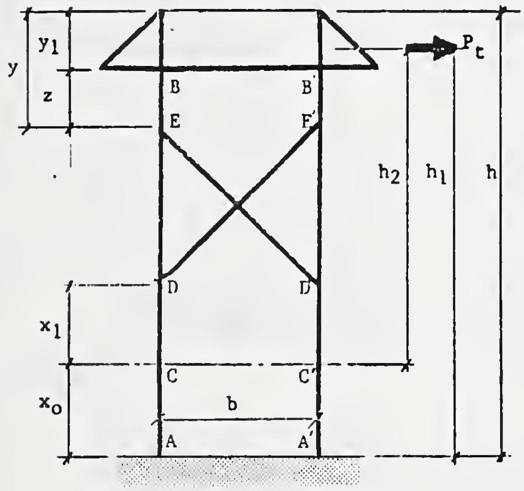


FIGURE 13-19

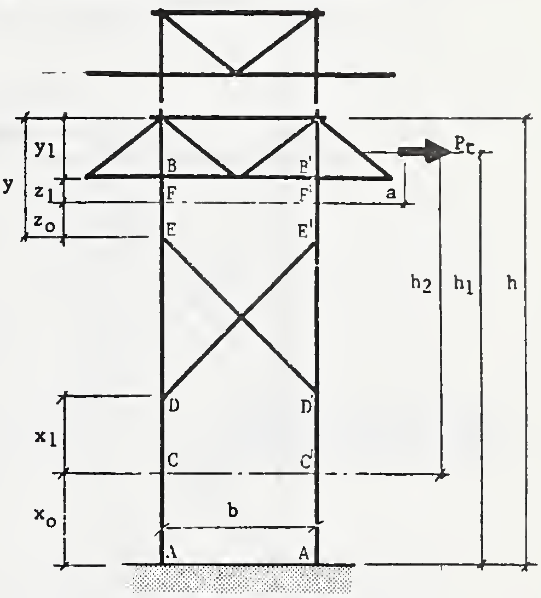


FIGURE 13-20

STRUCTURE 4
(Figure 13-20)

$$HS_B = \left[M_B - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_1)}{2}\right] / \left[\frac{(OCF)(p_t)(z_1)}{2}\right] \quad \text{Eq. 13-16a}$$

$$HS_E = \left[M_E - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_o)}{2}\right] / \left[\frac{(OCF)(p_t)(z_o)}{2}\right] \quad \text{Eq. 13-16b}$$

HS_D, HS_A = same as structure #2.

For uplift and bearing: same as structure #2.

For crossbrace:

$$HS_x = \left[125{,}800(b) - U + V\right] / \left[(OCF)(p_t)(h_2 - a)\right] \quad \text{(Metric) Eq. 13-16c}$$

$$HS_x = \left[28{,}300(b) - U + V\right] / \left[(OCF)(p_t)(h_2 - a)\right] \quad \text{(English) Eq. 13-16d}$$

where:

$U = 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6$

$V = 2(OCF)(F)(y-z_o)^2(2d_t + d_f)/6$

STRUCTURE 5
(Figure 13-21)

For crossbrace:

$$HS_x = \left[252{,}000(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / \left[(OCF)(p_t)(h_2)\right]$$ (Metric) Eq. 13-18a

$$HS_x = \left[56{,}500(b) - 2(OCF)(F)(h-x_o)^2(2d_t + d_c)/6\right] / \left[(OCF)(p_t)(h_2)\right]$$ (English) Eq. 13-18b

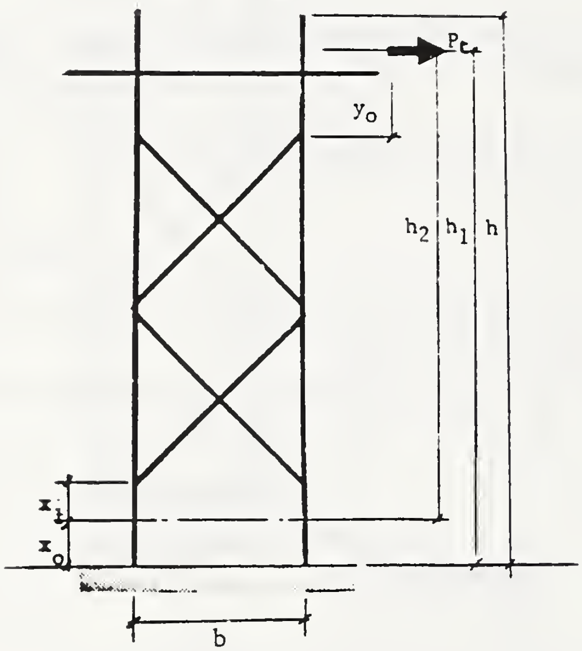


FIGURE 13-21

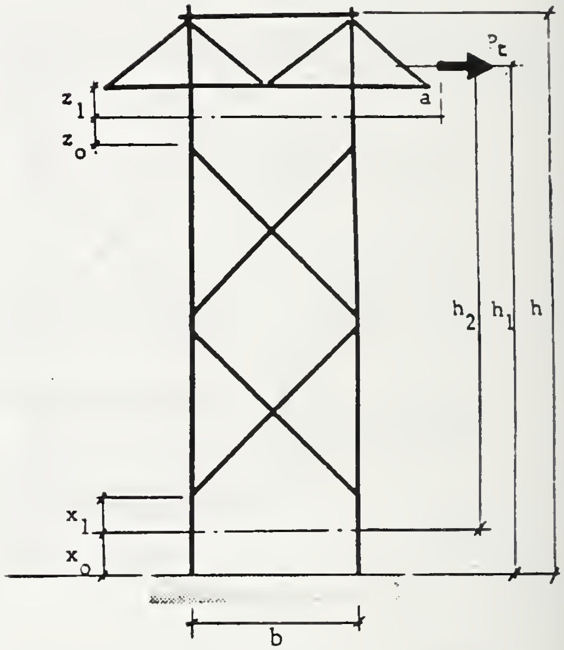


FIGURE 13-22

STRUCTURE 6
(Figure 13-22)

For crossbrace:

$$HS_x = \left[252{,}000(b) - U + V\right] / \left[(OCF)(p_t)(h_2-a)\right]$$ (Metric) Eq. 13-19a

$$HS_x = \left[56{,}500(b) - U + V\right] / \left[(OCF)(p_t)(h_2-a)\right]$$ (English) Eq. 13-19b

where:

U = same as structure #4.

V = same as structure #4.

13.9 Example of an H-frame Analysis: For the 161 kV structure shown below, determine the horizontal span based on structure strength and uplift and plot the horizontal versus vertical span for the pole top assembly.

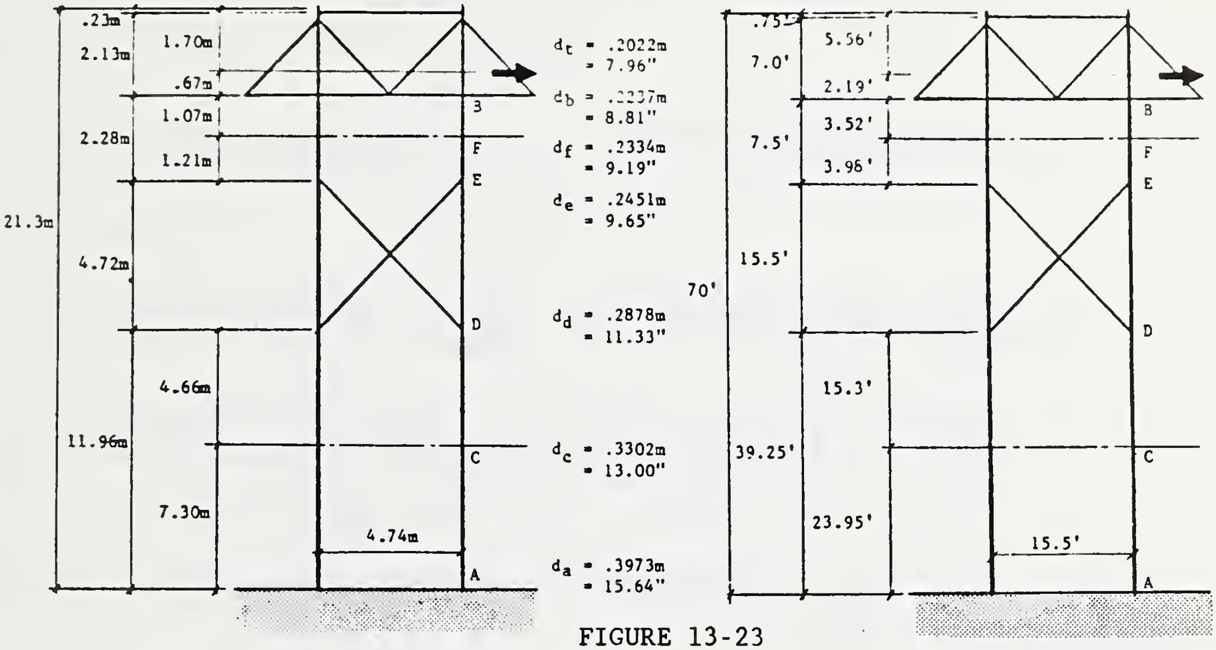


FIGURE 13-23

13.9.1 Given:

a. NESC heavy loading
High winds - 766 Pa (16 psf)
Heavy ice - 25.4 mm (1" radial)

b. Pole: Douglas fir 80-2
Cond: 795 kcmil 26/7
OHGW: 7/16 E.H.S.
R.S.: 244 M (800 ft.)

c. Conductor loads

N/m (lbs/ft):	Heavy Ldg. Dist.	High Wind	Heavy Ice
Transverse	10.255 (.7027)	21.559 (1.4773)	0
Vertical	30.557 (2.0938)	15.965 (1.0940)	54.221 (3.7154)
Tensions N (lbs)	46,300 (10,400)	N.A.	62,300 (14,000)

d. OHGW loads

N/m (lbs/ft):			
Transverse	6.980 (.4783)	8.464 (.5800)	0
Vertical	14.308 (.9804)	5.823 (.3990)	31.865 (2.1835)
Tensions N (lbs)	26,200 (5,900)	N.A.	33,400 (7,500)

e. Soil: Average. Presumptive skin friction (ultimate) of 250 psf for predominantly dry soil areas and using native backfill; 500 psf when aggregate backfill is used.

13.9.2 Solution for Heavy Loading District Loads: Maximum horizontal span based on structure strength:

Metric	English

a. Equivalent force p_t:

Metric:

$$p_t = 2p_g + 3p_c = 2(6.980) + 3(10.255) = 44.725 \text{ N/m}$$

English:

$$p_t = 2p_g + 3p_c = 2(.4783) + 3(.7027) = 3.065 \text{ lbs/ft.}$$

b. Determine location of equivalent load p_t:

Metric:

$$\text{Dist. from top} = \frac{2p_g(.23) + 3p_c(2.362)}{p_t} = 1.69 \text{ m}$$

English:

$$\text{Dist. from top} = \frac{2p_g(.75) + 3p_c(7.75)}{p_t} = 5.56 \text{ ft.}$$

c. Determine location of x_o, x_1, z_o, z for the X-brace location shown. All diameters, d_n, determined by Appendix F, Pages F-14 & F-15 and ratio x_o/x_1 or z_o/z determined by Appendix H.

For x_o, x_1:

Metric:

$$\frac{d_d}{d_a} = \frac{.2878}{.3973} = .72$$

$$\therefore \frac{x_o}{x} = .61$$

$$x_o = .61(11.96)$$

$$x_o = 7.29 \text{ m}$$

$$x_1 = 4.66 \text{ m}$$

and $d_c = .3302$ m

English:

$$\frac{d_d}{d_a} = \frac{11.33}{15.64} = .72$$

$$\therefore \frac{x_o}{x} = .61$$

$$x_o = .61(39.25)$$

$$x_o = 23.9 \text{ ft.}$$

$$x_1 = 15.3 \text{ ft.}$$

and $d_c = 13.0$ in.

For z_o, z:

Metric:

$$\frac{d_b}{d_e} = \frac{.2238}{.2451} = .91$$

$$\therefore \frac{z_o}{z} = .53$$

$$z_o = .53(2.29)$$

$$z_o = 1.21 \text{ m}$$

$$z_1 = 1.07 \text{ m}$$

and $d_f = .2334$ m

English:

$$\frac{d_b}{d_e} = \frac{8.81}{9.65} = .91$$

$$\therefore \frac{z_o}{z} = .53$$

$$z_o = .53(7.5)$$

$$z_o = 3.98 \text{ ft.}$$

$$z_1 = 3.52 \text{ ft.}$$

and $d_f = 9.19$ in.

d. Horizontal span limited by pole strength at B:

$$HS_B = (M_B - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_1)}{2}) / \frac{(OCF)(p_t)(z_1)}{2}$$

a. M_B = 60,600 N-m M_B = 44,700 ft-lbs

(Metric)

b. $$HS_B = \left(60,600 - \frac{4(191.5)(4.65-1.21)(.2022+.2334)(1.07)}{2}\right) / \left(\frac{(4)(44.725)(1.07)}{2}\right)$$

= 625 m

(English)

$$HS_B = \left(44,700 - \frac{4(4)(15.25-3.98)(.663 +.766)(3.52)}{2}\right) / \left(\frac{4(3.065)(3.52)}{2}\right)$$

= 2,050 ft.

e. Horizontal span limited by pole strength at E:

$$HS_E = M_E - \frac{(OCF)(F)(y-z_o)(d_t + d_f)(z_o)}{2} / \frac{(OCF)(p_t)(z_o)}{2}$$

a. $ME = M_{cap} - M_{bh}$

M_E = 79,700 - 11,400 N-m M_E = 58,800 - 8,400 ft-lbs
M_E = 68,300 N-m M_E = 50,400 ft-lbs
(M_{bh} from Appendix F)

(Metric)

b. $$HS_E = \left(68,300 - \frac{4(191.5)(4.65-1.21)(.2022 + .2334)(1.21)}{2}\right) / \left(\frac{(4)(44,725)(1.21)}{2}\right)$$

= 624 m

(English)

$$HS_E = \left(50,400 - \frac{4(4)(15.25- 3.98)(.663+ .766)(3.98)}{2}\right) / \left(\frac{4(3.065)(3.98)}{2}\right)$$

= 2,044 ft.

f. For horizontal span limited by pole strength at locations D and A, similar calculations can be made. The results are as follows:

HS_D = 238 m HS_D = 780 ft.
HS_A = 488 m HS_A = 1600 ft.

g. For horizontal span limited by strength of the crossbrace:

$HS_X = [125{,}800(b) - U+V]/[(OCF)(p_t)(h_2-a)]$ (Metric)

$HS_X = [28{,}300(b) - U+V]/[(OCF)(p_t)(h_2-a)]$ (English)

where:
$U = 2(OCF)(F)(h-x_o)^2(2d_t+d_c)/6$
$V = 2(OCF)(F)(y-z_o)^2(2d_t+d_f)/6$

$U = 2(4)(191.5)(21.34 - 7.29)^2(2(.2022)+.3302)/6$ (Metric)
$= 37{,}026$ N-m

$U = 2(4)(4)(70 - 23.9)^2(2(.663)+1.083)/6$ (English)
$= 27{,}305$ ft-lbs.

$V = 2(4)(191.5)(4.65 - 1.21)^2(2(.2022)+.2334)/6$ (Metric)
$= 1927$ N-m

$V = 2(4)(4)(15.25 - 3.98)^2(2(.663)+.766)/6$ (English)
$= 1417$ ft-lbs.

$HS_X = [125{,}800(4.72)-37{,}026+1927]/[(4)(44.725)(10.60)]$ (Metric)

$= 294$ m

$HS_X = [28{,}300(15.5)-27{,}305+1417]/[(4)(3.065)(34.78)]$ (English)

$= 968$ ft.

13.9.3 <u>Solution for Heavy Loading District Loads</u>: Maximum span limited by pole top assembly follows:

a. From Equation 13-10.

$$\frac{W_t(VS)}{\sin\alpha} \leq 88{,}900 \text{ N } (20{,}000 \text{ lbs.})$$

$$VS = \frac{88{,}900\sin 39° - 4(600)}{30.557(4)} \qquad VS = \frac{20{,}000\sin 39° - 4(135)}{2.0938(4)}$$

$$= 438 \text{ m} \qquad = 1440 \text{ ft.}$$

b. From Equation 13-8:

$$\frac{w_c(VS)}{2\sin\alpha} + \frac{p_t(a)(HS)}{b\sin\alpha} \leq 88{,}900 \text{ N } (20{,}000 \text{ lbs.})$$

$$\frac{4(30.557)(VS)}{2\sin 39°} + \frac{4(44.725)(.67 + 1.07)(HS)}{4.72\sin 39°} \leq 88{,}900 \text{ N} \qquad \text{(Metric)}$$

$$97.11VS + 104.80HS \leq 88{,}900 \text{ N}$$

$$\frac{4(2.0938)(VS)}{2\sin 39°} + \frac{4(3.065)(2.19 + 3.52)(HS)}{15.5\sin 39°} \leq 20{,}000 \text{ lbs.} \qquad \text{(English)}$$

$$6.65VS + 7.18HS \leq 20{,}000 \text{ lbs.}$$

(By inspection, Equation 13-8 does not control design).

13.9.4 <u>Solution for Heavy Loading District Loads</u>: Maximum span limited by uplift follows. Assume dry native backfill, safety factor of 4.

$$HS(p_t)(h_2) - VS(w_g)(b) - 1.5VS(w_c)(b) = W_1(b) + W_p(b) + X - Y \qquad \text{(Eq. 13-14g)}$$

where:

$W_1 = F_s(D)(d_{avg})\pi/SF$	$W_1 = F_s(D)(d_{avg})\pi/SF$
$= 11{,}780$ N	$= 2649$ lbs.

W_p = Wt. of one pole and half the weight of pole top assembly and crossbrace.

= 20,500 N	= 4200 + 800/2 = 4600 lbs.
$X = F(h-x_o)(d_t+d_c)(x_o)$	$X = F(h-x_o)(d_t+d_c)(x_o)$
= 10,440 N-m	= 7705 ft-lbs.
$Y = 2(F)(h^2)(2d_t+d_a)/6$	$Y = 2(F)(h^2)(2d_t+d_a)/6$
= 23,290 N-m	= 17,182 ft-lbs.

The equations are as follows:

$551HS - 283VS = 139{,}500$	$124.13HS - 63.88VS = 102{,}900$

(For VS=0, maximum HS=830 ft.)

13.9.5 Check for Extreme Wind Conditions:

a. Span limitations based on pole strength controlled by NESC conditions.

b. By inspection, maximum vertical span limited by extreme ice conditions does not control.

c. Span limitations based on uplift (controls).

For dry native backfill, safety factor of 1.5 assumed, the following equations result:

$989.1HS - 140.5VS = 193{,}662$ $\qquad$ $222.2HS - 25.4VS = 142{,}862$

(For VS=0, maximum HS=640 ft.)

For aggregate backfill, safety factor of 1.5 assumed:

$989.1HS - 140.5VS = 342{,}000$ $\qquad$ $222.2HS - 25.4VS = 252{,}400$

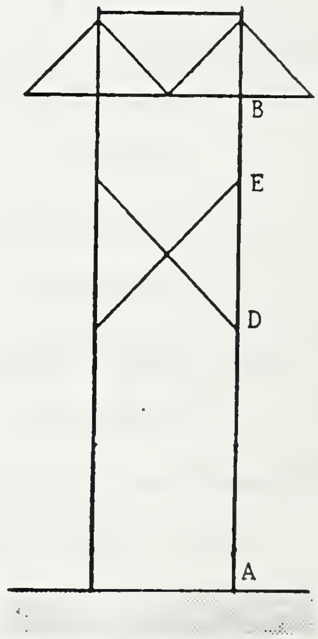
(For VS=0, maximum HS=1,135 ft.)

When considering uplift, it is sometimes prudent to base calculations on the minimum vertical span as limited by insulator swing.

13.9.6 Summary:

HS_A = 488 m (1600 ft.)
HS_D = 238 m (780 ft.)
HS_E = 624 m (2044 ft.)
HS_B = 625 m (2050 ft.)
HS_X = 287 m (960 ft.)

Dry native backfill:
HS_{uplift} = 346 m (1,135 ft.), max.
VS = 0 m (0 ft.)
$VS_{poletop}$ = 438 m (1,440 ft.), max.



A more efficient design could be achieved by moving the crossbrace.

14. <u>GUYED STRUCTURES</u>:

14.1 <u>Introduction</u>: When a wood structure is guyed, loading on the poles is due to the combined action of vertical and horizontal forces. Vertical forces on the pole are due to the vertical component of the tension in the guy and the weight of the conductors and insulators. Horizontal loads result from transverse loads due to wire tensions at angle structures and from unbalanced vertical and longitudinal forces from deadending.

Bisector guys are usually used on small angle structures, whereas head and back guys are used on large angle structures and double deadends. Angles between 10 and 45 degrees may be turned on what is called a "running" vertical angle, utilizing bisector guys. Above 45 degrees unequal stresses will be set up in the conductor where it attaches to the suspension insulator clamp. The sharper the angle or bend in the conductor at the clamp, the more unequal the stresses will be. Any unbalanced longitudinal wire tension loads on double deadend and large angle structures can be more effectively carried by head and back guys. For large angle structures, the transverse load due to wire tension loads will be a heavy permanent load, therefore, head and back guys will be more effective in carrying this load.

An example of a deadend structure is shown below, in which the conductors are connected to the structure by strain insulators. There are two different types of deadend structures - a deadend and a "full" deadend structure.

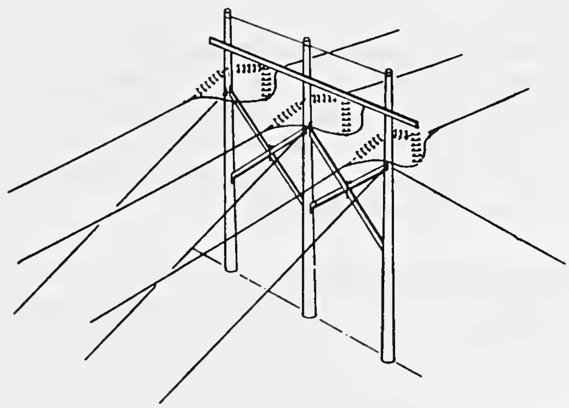


FIGURE 14-1: DEADEND STRUCTURE

A deadend structure need only be designed to withstand the load resulting from the difference in tensions of the conductor for the forward and back spans. This condition occurs where there is a change in ruling spans. For a full deadend structure, the guys and anchors are designed to withstand the resultant load when the conductors are assumed to be broken or slack on one side of the structure. As mentioned in Chapter 10, it is suggested that full deadend structures be located every five to ten miles to prevent progressive cascading-type failures.

In general, guys and anchors should be installed at deadends, angles, long spans where pole strength is exceeded, and at points of excessive unbalanced conductor tension. The holding power and condition of the soil (whether wet or dry, packed or loose, disturbed or undisturbed, etc.) and the ability of the pole to resist buckling and deflection should be considered.

14.2 Overload Capacity Factors: In Chapter 11, Tables 11-3 and 11-4 give recommended minimum overload capacity factors associated with the design of guyed tangent and angle structures. The following table summarizes the application of overload capacity factors for guys and anchors.

TABLE 14-1
APPLICATION OF OCF FOR GUYED STRUCTURES
(GUYS AND ANCHORS)

	NESC	Recommended REA OCF*
Loading Districts	$(2.50)(a+b) + 1.65c = .90\ G\cos\phi$	
	or $(2.78)(a+b) + 1.83c = G\cos\phi$	$4(a+b) + 2c = G\cos\phi$
Extreme Winds	$(a+b) + c = .90\ G\cos\phi$	
	or $1.1(a+b) + 1.1c = G\cos\phi$	$(1.5)(a+b) + 1.33c = G\cos\phi$

*Lower overload factors may be used where justified but should in no case be less than NESC overload factors.

In the above table:
- a = transverse wind load on the conductor.
- b = transverse wind load on pole surface.
- c = transverse component of wire tension load.
- G = the calculated force in the guy, considering guy lead. The rated breaking strength of the guy wire (G_u) and anchor capacity (A_u) must equal or exceed this value.
- $\cos\phi$ = true guy slope with horizontal.

14.2.1 Alternate Strength and Load Factors: Tables 11-5 and 11-6 give alternate recommended strength and load factors for guys and anchors. Table 14-1a summarizes these as follows:

TABLE 14-1a
ALTERNATE METHOD APPLICATION OF LOAD FACTORS
AND STRENGTH FACTORS FOR GUYED STRUCTURES (GUYS AND ANCHORS)

	NESC	Recommended REA Load Factors
Loading Districts	see Table 14-1	$2.50(a+b) + 1.33c = .65G\cos\phi$
		or $3.85(a+b) + 2.05c = G\cos\phi$
Extreme Winds	see Table 14-1	see Table 14-1

14.2.2 Longitudinal strength ("in general" category) is applicable to crossings and locations where unequal spans and unequal vertical loadings may occur. At crossings, the NESC states that wood tangent structures which meet

transverse strength requirements without guys, shall be considered as having the required longitudinal strength, provided that the longitudinal strength of the structure is comparable to the transverse strength of the structure. If there is an angle in the line, the wood structure will have the required longitudinal strength provided:

a. The angle is not over 20 degrees.

b. The angle structure is guyed in the plane of the resultant conductor tensions.

c. The angle structure has sufficient strength to withstand, without guys, the transverse loading which would exist if there were no angle at that structure with an overload factor of 4.0.

Guying and anchors for distribution underbuild are to be Grade B construction. Refer to Chapter 16 for additional information concerning underbuild.

14.3 Clearances: Recommended clearances to be maintained between any phase conductor and guy wires are indicated in Table 14-2. Refer to Chapter 7 for further details.

TABLE 14-2

	NESC Clearances		Recommended REA Clearances (mm, in)					
Voltage	mm	(in)	No Wind		6 psf wind		Ext. wind	
34.5	318	(12.5")	483	(19")	330	(13")	76	(3")
46	389	(15.3")	483	(19")	406	(16")	76	(3")
69	556	(21.9")	635	(25")	559	(22")	127	(5")
115	864	(34.0")	1067	(42")	889	(35")	254	(10")
138	1016	(40.0")	1219	(48")	1041	(41")	305	(12")
161	1168	(46.0")	1524	(60")	1194	(47")	356	(14")
230	1631	(64.2")	(1803-2108)	(71"-83")	1651	(65")	508	(20")

14.4 Design

14.4.1 Bisector Guys: For structures utilizing bisector guys, the guys must sustain the resultant transverse load due to longitudinal wire tension loads, given below:

$c = 2(T)\sin \Theta/2$, where T is the maximum design tension and Θ is the line angle.

The transverse load due to wind on the conductors for an angle structure is given as:

$a = (p)(HS)(\cos \Theta/2)$, where "p" is the wind load in N/m (lb/ft), HS is the horizontal span, and Θ is the line angle. Cos $\Theta/2$ could be set equal to one.

Wind on the structure should be converted to a horizontal force "b" at the point of guy attachment.

14.4.2 <u>Head and Back Guys</u>: Deadends, double deadends, and large angle structures will normally require head and back guys. For tangent deadends and double deadends, the transverse strength of the structure must be sufficiently strong to carry the appropriate wind load. In some cases, bisector guys or crossbraces may have to be used to meet transverse strength requirements. The tension in the guy should take into account the slope of the guy.

14.5 <u>Pole Strength</u>: Once the tension in the guy wire has been calculated, the compressive strength of the pole should be checked.

14.5.1 <u>Stability Concept</u>: The selection of structural members is based on three characteristics: strength, stiffness, and stability. When considering a guyed wood pole, the possible instability of the structure should be considered.

An example of stability is to consider the axial load carrying capabilities of the two rods shown below.

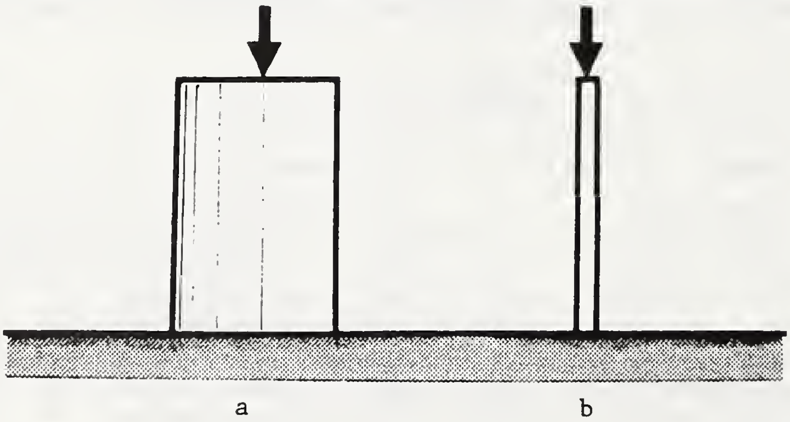


FIGURE 14-2: COMPARISON OF RODS TO SHOW STABILITY CONCEPT

The rod on the left is unquestionably "more stable" to axial loads than the rod on the right. The consideration of material strength alone is not sufficient to predict the behavior of a long slender member. As an example, the rod on the right might be able to sustain 4450 N (1000 lbs.) axial load when considering strength (ultimate compressive stress times area), but could only sustain 3336 N (750 lbs.) when considering stability of the system. Rod "b" is more likely to become laterally unstable through sidewise buckling.

14.5.2 <u>Critical Column Loads</u>: In transmission structures, the guyed pole acts as a column, sustaining axial loads induced in the pole from vertical guy components. The taller the pole, the less load the guyed pole can sustain in compression before the structure becomes "unstable".

Stability of a column can be thought of in one of two ways:

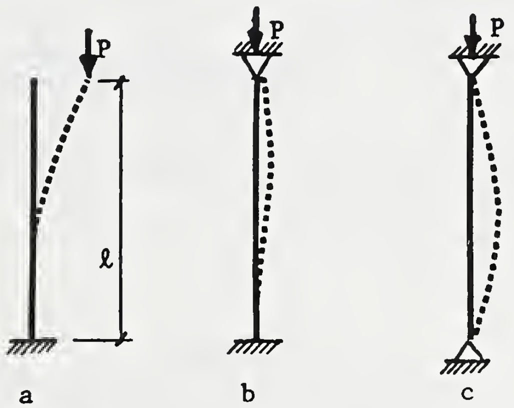
a. The column is unstable when the axial force would cause large lateral deflections even when the lateral load was very small.

b. A column subjected to an axial force is stable if a lateral force is applied and a small deflection is produced, but disappears when the lateral force is removed, and the bar returns to its straight form. If P (axial) is gradually increased, a condition is reached in which the straight form of equilibrium becomes unstable and a small lateral force will produce a deflection which does not disappear when the lateral force is removed. The "critical" load is then the axial force which causes buckling or collapses due to any bowing or lateral disturbance..

14.5.3 Calculation of Buckling Loads: In general, for long slender columns, the critical buckling load is determined from:

$$P_{cr} = \frac{\pi^2 EI}{(k\ell)^2}$$ (P_{cr} is independent of the yield stress of the material).

where for the various end conditions, P_{cr} is idealized below:



$P_{cr} = \dfrac{\pi^2 EI}{4\ell^2}$ (k = 2.0)

$P_{cr} = \dfrac{2\pi^2 EI}{\ell^2}$ (k = .7)

$P_{cr} = \dfrac{\pi^2 EI}{\ell^2}$ (k = 1.0)

k = theoretical coefficient of unbraced length of column for various end conditions, already in P_{cr}.

FIGURE 14-3: EFFECTIVE UNBRACED LENGTH FOR VARIOUS END CONDITIONS

There are several assumptions made in the above calculations: the column is perfectly straight initially; the axial load is concentrically applied at the end of the column; the column is assumed to be perfectly elastic and stresses do not exceed the proportional limit; the column is uniform in section properties.

For a guyed wood pole, all the assumptions are violated. As such, the engineer must apply appropriate safety factors to account for realistic cases and the variability of wood.

With regard to the assumption of uniform section, the critical buckling load can be estimated by one of two methods:

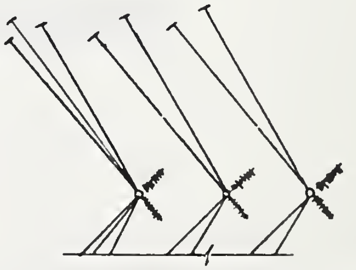
a. Assume that the moment of inertia in the above equation is at the section of the pole 2/9 the distance from the top (or point of guy attachment) to the bottom.

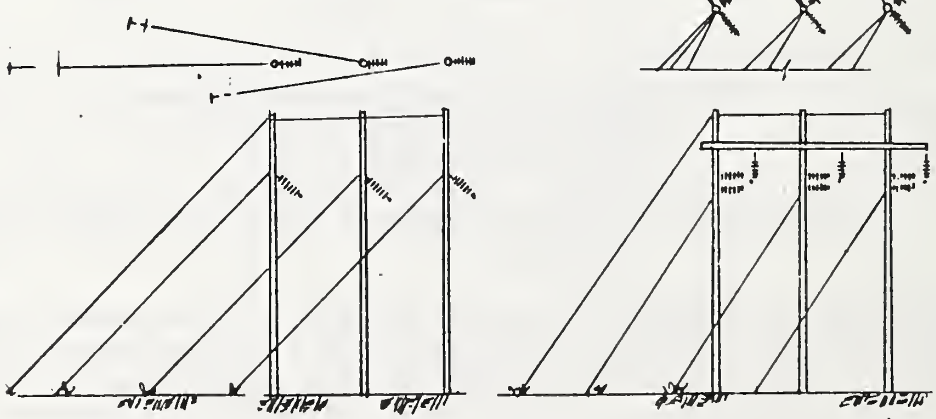
b. Assume that the moment of inertia is at the section of the pole 1/3 the distance from the top (or point of guy attachment) to the bottom. (American Institute of Timber Construction).

14.5.4 <u>Safety Factor</u>: For NESC light, medium, and heavy district loads (without overload factors or load factors), REA recommends that for tangent structures and small angle structures, a minimum factor of safety of 2 be attained. For deadends and large angles the engineer should strive for a factor of safety of 3.0 against buckling. For heavy ice conditions, it is recommended that a safety factory of 1.33 be attained.

14.5.5 <u>General Application Notes</u>: For unbraced guyed single poles using bisector guys, certain assumptions are made as to the end constraints. In the direction of the bisector guy, the structure appears to be pinned at the point of the guy attachment and fixed at the base. However, 90° to the bisector guy, the structure appears to be a cantilevered column. Since the conductors and phase wires offer some constraint, the actual end conditions may be between fix-free and fixed-pinned. When checking buckling, it is suggested that the end conditions of pinned-pinned be assumed.

Buckling Mode	End Conditions	
	Bisector Guyed	In-line Guyed
Longitudinally	pinned-pinned	pinned-fixed
Transversely	pinned-fixed	pinned-fixed





Bisector Guyed Structure   In-line Guyed Structure

FIGURE 14-4: END CONDITIONS FOR BISECTOR AND IN-LINE GUYED STRUCTURES

For in-line guyed poles, the structure appears to be pinned at the point of guy attachment and fixed at the base in both directions (Figure 14-4).

In many instances, axial loads are applied intermittently along the pole. In Figure 14-5a, the static wire and phase wire are guyed at their respective locations. The axial loads acting on the pole on the left are applied as shown in Figure 14-5b.

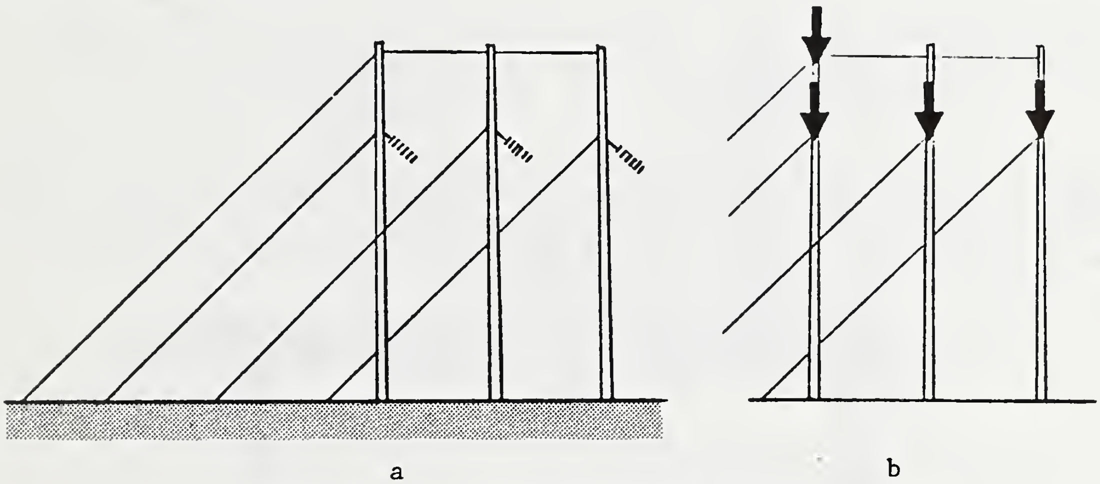


FIGURE 14-5: REPRESENTATION OF AXIAL LOADS

In such instances, the usual engineering practice is to assume an unbraced length from the groundline to the lowest guy attachment and the induced axial load in the pole equal to the sum of all axial loads included by the vertical component of the guys.

When the structure is considered as a double deadend or large angle, the poles, guys, and anchors must sustain the full deadend load with an appropriate overload factor. For the tangent double deadend shown in Figure 14-6, the poles must sustain the maximum axial load which might occur if all phase conductors on one side of the structure were removed. (See Figure 14-7a and 14-7b). However, to "double account" the loads, as shown in Figure 14-7c would be too conservative.

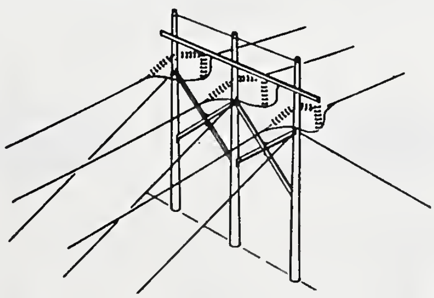


FIGURE 14-6: TANGENT DOUBLE DEADEND

In many instances, deadends and large angle structures will require a class higher pole than what is used as the base class pole for the line. There are ways to control or reduce the pole class needed at deadends and large angles.

a. Relocate and/or increase height of tangent structures adjacent to guyed angle and deadends. This would allow the use of shorter poles at guyed structures, and as a result, a lower class pole, but with no sacrifice in safety.

b. Decrease the guy slope will decrease the vertical load component on the pole.

As a note, angle and deadend structures usually comprise about 5 percent of the total structures of a line. Therefore, the use of conservative safety factors for these critical structures results in a greater overload margin without significantly affecting the total cost of the transmission line.

The engineer should consider guying single pole structures which are used for small angles, even if the pole has adequate strength to carry the load. Wood poles have a tendency to "creep" with time when subjected to a sustained load. For the case shown below, engineering judgment should be used to determine whether or not two guys should be used.

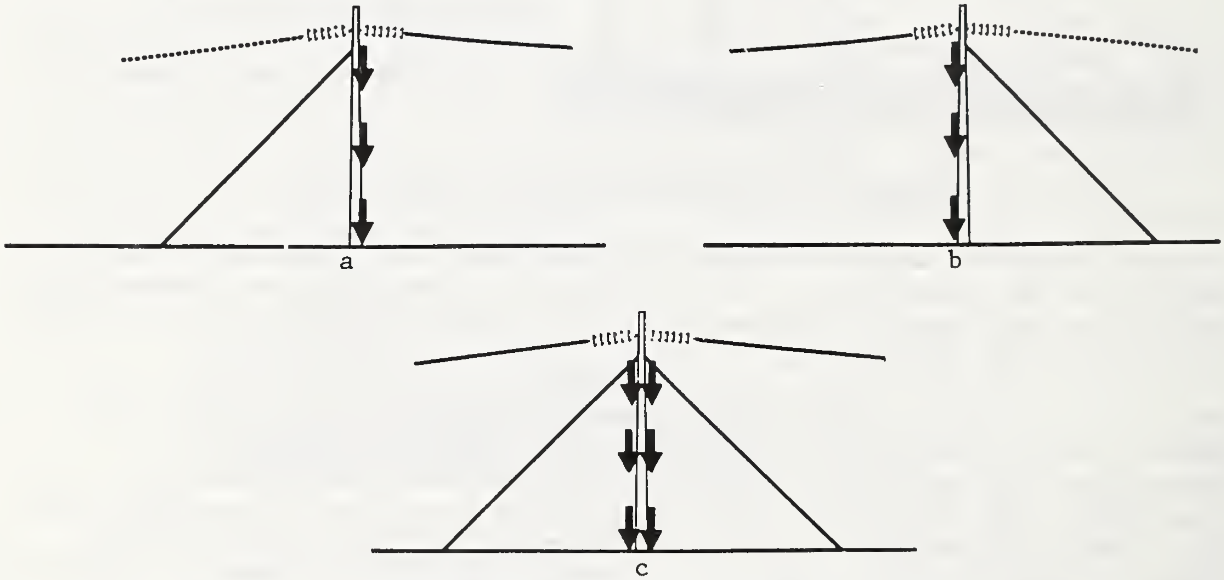


FIGURE 14-7: REPRESENTATION OF AXIAL LOADS (a & b) AND DOUBLE ACCOUNTING OF LOADS (c)

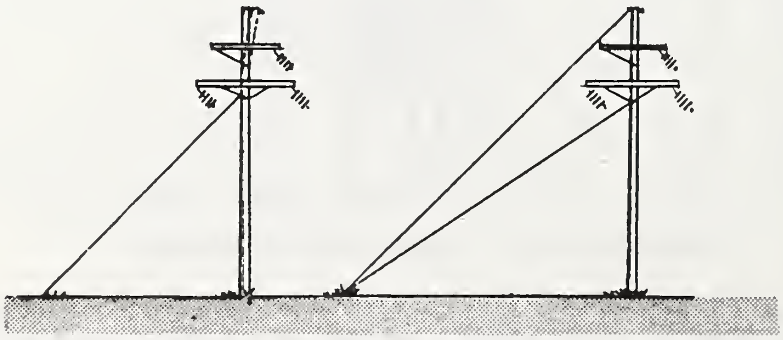
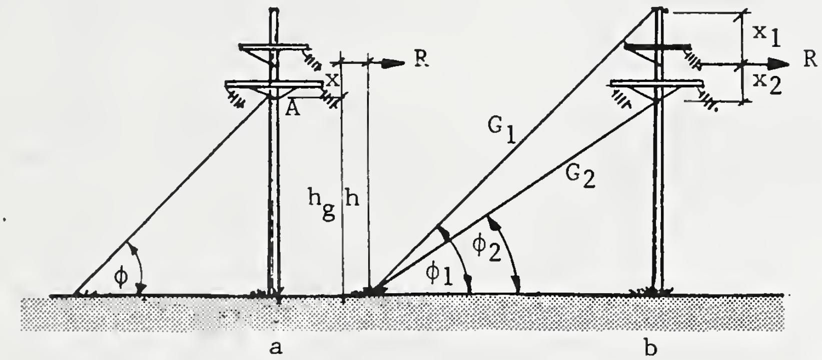


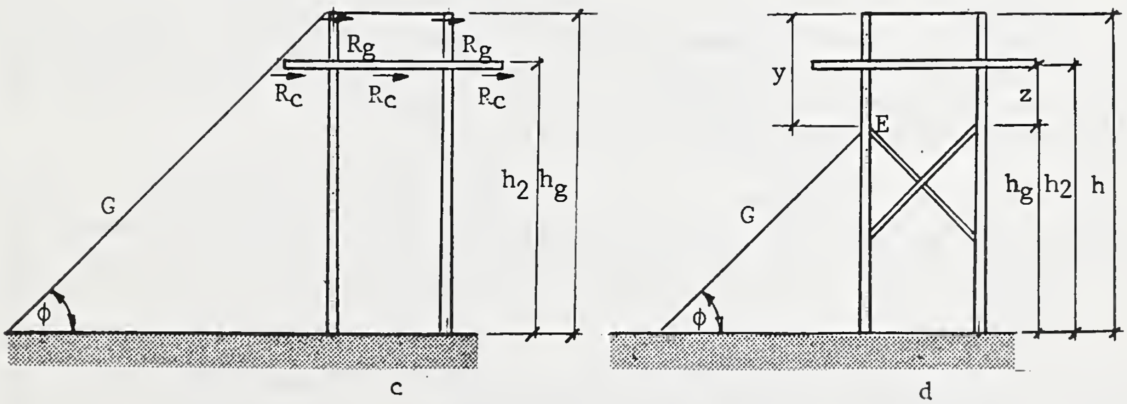
FIGURE 14-8: GUYED SINGLE POLE STRUCTURES

When structures utilize several guys and possibly various bracing to sustain loads, the engineer must determine appropriate methods of analysis and distribution of forces in the guys. Examples of suggested methods for calculating forces in guys (G) and in the structures follow. The total transverse load (R) which the structure and guy must sustain is due to the wind on the conductors and structure and due to longitudinal wire tension load with appropriate overload factors. The poles should be checked for buckling.



$G = Rh/(h_g \cos\phi)$ $\qquad$ $G_1 = Rx_2/(x_1+x_2)\cos\phi_1$

$M_A = Rx$ $\qquad$ $G_2 = Rx_1/(x_1+x_2)\cos\phi_2$



$G = [3R_c(h_2)/h_g+2R_g]\ /\cos\phi$ $\qquad$ $G = [(2R_c h_2/h_g)+R_g(h/h_g)]\ /\cos\phi$

$M_E = (2R_c)z+(R_g)y$

FIGURE 14-9: SUGGESTED METHODS FOR CALCULATING FORCE IN GUYS

14.6 Anchors: The holding power of the anchor will largely depend on the condition of the soil, whether it is wet or dry, packed or loose, disturbed or undisturbed. Since soils vary considerably between locations, the holding power of an anchor will also vary considerably.

In areas where there may be a fluctuating water table, the capacity of the anchors should take into account the submerged unit weight of the soil. If at any time the holding power of an anchor is questionable due to variable soil conditions, the anchor should be tested. The primary types of anchors include log anchors, plate anchors, power screw anchors, and rock anchors. The selection of the appropriate anchor will largely depend on the type of soil condition.

14.6.1 Log Anchor Assemblies: The two log anchors in the construction drawings are respectively 8"x5'-0" and 8"x8'-0", and have an ultimate holding power of 71,000 N (16,000 lbs.) and 142,000 N (32,000 lbs.). These logs, using one or two anchor rods, may be used in combination to provide sufficient holding power for guys. "Average" soil is considered to be medium dense, coarse sand and stiff to very stiff silts and clays. As such, log anchors should be derated or should not be used in soils of soft clay, or organic material, saturated material or loose sand or silt.

14.6.2 Plate Anchors: The plate anchor assembly as shown in Drawing TA-3P, is rated at an ultimate holding power of 71,000 N (16,000 lbs.) and 106,500 N (24,000 lbs.). In firm soils, where the engineer would like to minimize digging, plate anchors may prove economical.

14.6.3 Power Screw Anchors: Screw anchors are being used more often because of their easy installation. They are most appropriate for locations where firm soils exist at large depths. Holding capacity may be questionable in soils having rocks.

14.7 Drawings: For each line, a summary drawing should be prepared showing the arrangement of guys for each type of structure to be used. The drawing will greatly facilitate the review of the plan and profile, and simplify the construction of the line. See page 14-13 for an example of such a drawing. Several items should be noted in the drawing.

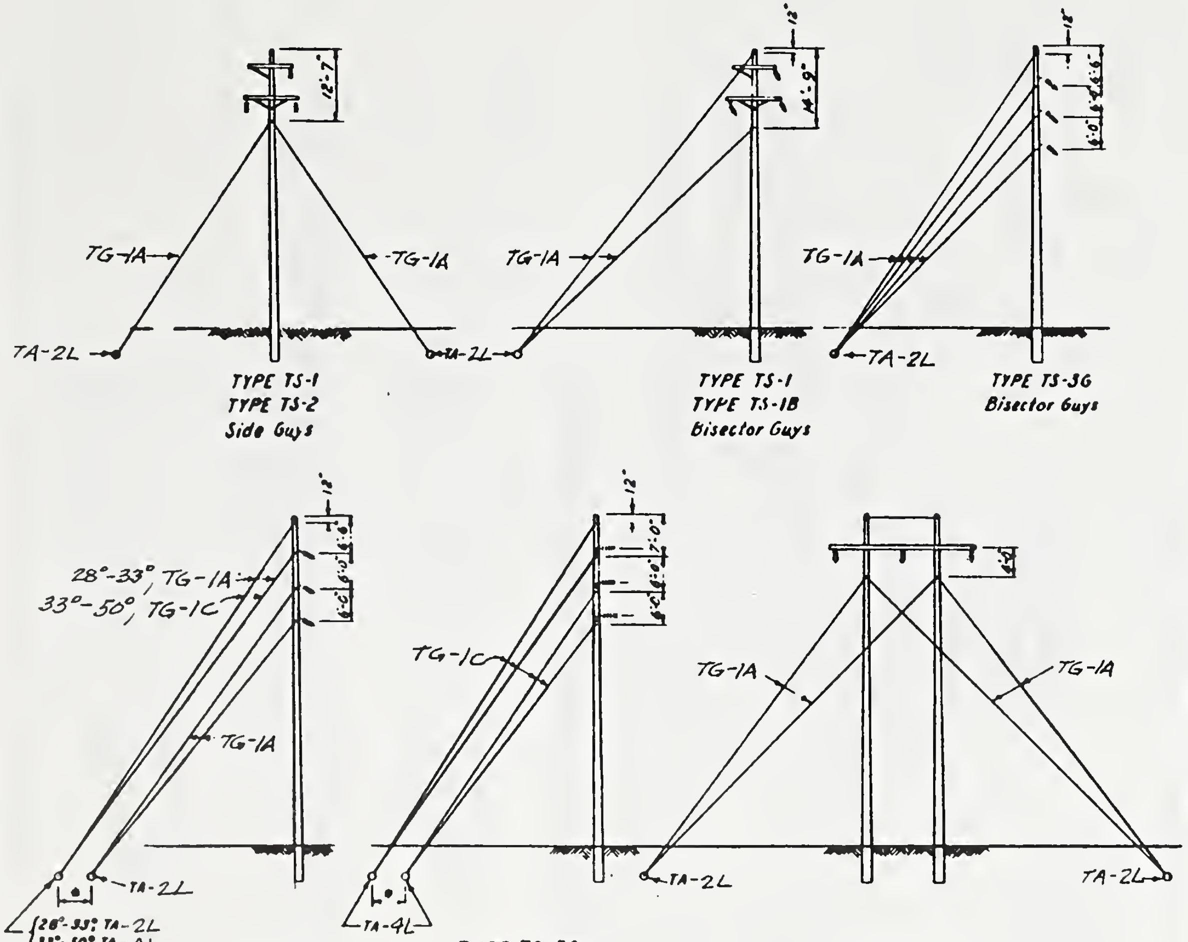
The guys required for various line angles are based on assumed spans. Since actual spans will vary, the guying requirements shown will not be exact for all conditions. Sometimes, it is desirable to make a guying guide for each angle structure, which relates horizontal span to the angle of the line (see example 14-1).

The drawing also shows (1) points of attachment of the guy to the pole, (2) slope of the guys, (3) type of structure, and (4) guys and anchors required.

CONDUCTOR: Design Tension - 3337 Lbs., Size - 3/0
Material - ACSR, Stranding - 6/1
GROUND WIRE: Design Tension - 3700 Lbs., Size - 3/8"
Material - H.S. Steel, Stranding - 7
LOADING: 1/2" Ice, + 4 Lb. Wind + Constant (.31) at 0°F.
RULING SPAN: 600'   STANDARD POLE: 50' Class 2
MINIMUM GROUND CLEARANCE: 21'
VOLTAGE: 69 KV.

NOTES:

1. Slope guys 45°. If other slopes are occasionally used, this should be shown on the plan and profile drawing.
2. • Minimum spacing between anchors shall be sufficient to provide maximum holding power for each anchor.



TYPE TS-1
TYPE TS-2
Side Guys

TYPE TS-1
TYPE TS-1B
Bisector Guys

TYPE TS-3G
Bisector Guys

TYPE TS-4G
Bisector Guys

TYPE TS-5G
Head and Back Guys

TYPE TH-1
Side Guys

GUYS BASED ON 500' LEVEL GROUND SPAN				
TYPE STRUCTURE	LINE ANGLE	GUYS REQUIRED	ANCHORS REQUIRED	GUY LOCATION
TS-1	0°	1-TG-1A	1-TA-2L	Each Side
TH-1	0°	2-TG-1A	1-TA-2L	Each Side
TS-1	0°-4°	1-TG-1A	1-TA-2L	Bisector
TS-2	0°-4°	1-TG-1A	1-TA-2L	Bisector
TS-1B	4°-12°	2-TG-1A	1-TA-2L	Bisector
TS-3G	12°-28°	4-TG-1A	1-TA-4L	Bisector
TS-4G	28°-33°	4-TG-1A	2-TA-2L	Bisector
TS-4G	33°-50°	2-TG-1A 2-TG-1C	1-TA-2L 1-TA-4L	Bisector
TS-5G	50°-Up	4-TG-1C	2-TA-4L	Head and Back

SPECIMEN DRAWING ONLY
(Not For Use As A Construction Drawing)
ARRANGEMENT OF GUYS AND DESIGN SUMMARY SHEET
FOR SUSPENSION TYPE STRUCTURES

Scale: None		Date:
		TM-10

14.8 Example 14-1: Develop guying guides for TH-12 161 kV structure.

14.8.1 Given:

a. NESC heavy loading
High winds - 766 Pa (16 psf)
Heavy ice - 25.4 mm (1" radial)

b. Pole: Douglas fir 80-2
Cond: 795 kcmil 26/7
OHGW: 7/16" E.H.S.
R.S.: 244 m (800 ft.)

c. Conductor loads

N/m (lbs/ft):	Heavy Ldg. Dist.	High Wind	Heavy Ice
Transverse	10.255 (.7027)	21.559 (1.4773)	0
Vertical	30.557 (2.0938)	15.965 (1.0940)	54.221 (3.7154)
Tensions N(lbs.)	46,300 (10,400)	N.A.	62,300 (14,000)

d. OHGW loads

N/m (lbs/ft):			
Transverse	6.980 (.4783)	8.464 (.5800)	0
Vertical	14,308 (.9804)	5.823 (.3990)	31.865 (2.1835)
Tensions N (lbs.)	26,200 (5,900)	N.A.	33,400 (7,500)

e. Guy wire: 7/16" E.H.S. Ultimate tension = 92,500 N (20,800 lbs.). Horizontal strength with 1/1 lead = 65,500 N (14,700 lbs.).

Anchors: 8,000 lbs. and 16,000 lbs. Ultimate capacity = 71,000 N (16,000 lbs.) and 142,000 N (32,000 lbs.). Horizontal strength with 1/1 lead = 50,000 N (11,300 lbs.) and 100,000 N (22,600 lbs.) respectively.

f. Soil: Average. Presumptive ultimate bearing capacity of 200 kPa (approximately 4,000 psf).

14.8.2 Solution for Heavy Loading District:

		Metric	English
a. Wind on the wires			
	Conductor:	$a = 10.255(HS)(\cos \Theta/2)$	$a = .7027(HS)(\cos \Theta/2)$
	OHGW:	$a = 6.980(HS)(\cos \Theta/2)$	$a = .4783(HS)(\cos \Theta/2)$

b. Wind on the pole: $b \doteq 875$ N $b \doteq 196$ lbs.
"b" is based on a 95-H1 pole with the guy located 23 m (75.5 ft.) from the ground. The equivalent horizontal load, "b", at this location is determined by Mwp/lever arm.
$b = 20{,}000$ N-m/23 m $b = 14{,}760$ ft-lbs/75.5 ft.

		Metric	English
c. Wire tension loads			
	Conductor:	$c = 2(46{,}300)\sin \Theta/2$	$c = 2(10{,}400)\sin \Theta/2$
	OHGW:	$c = 2(26{,}200)\sin \Theta/2$	$c = 2(5{,}900)\sin \Theta/2$

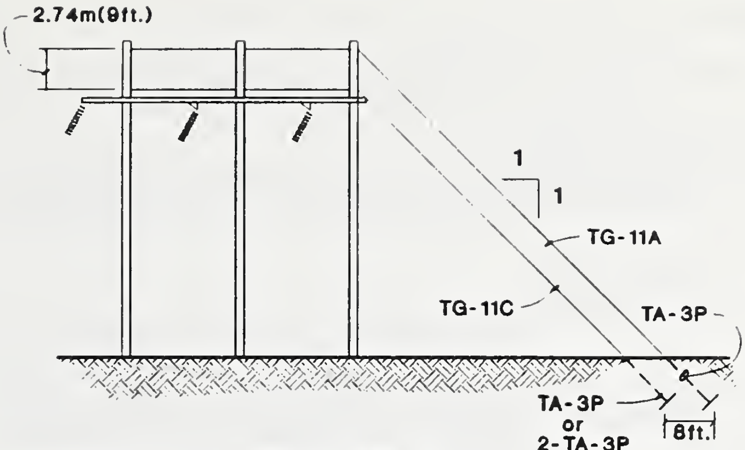


FIGURE 14-10: STRUCTURE TH-12

METRIC

d. General equation: 4(a+b)+2c = Gcosϕ

For the conductor:
4[(10.255)(HS)(cos Θ/2) + (875)] + 2 [2(46,300)(sin Θ/2)] = Gcosϕ
3,500 + (41.020)(HS)(cos Θ/2) + (185,200)(sin Θ/2) = Gcosϕ
For the OHGW:
4[(6.980)(HS)(cos Θ/2)+(neg.)] + 2 [2(26,200)(sin Θ/2)] = Gcosϕ
(27.920)(HS)(cos Θ/2) + (104,800)(sin Θ/2) = Gcosϕ

Case 1: Using 1 guy wire and 1 anchor for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:
3(3,500) + 3(41.020)(HS)(cos Θ/2) + 3(185,200)(sin Θ/2)≤Gcosϕ
10,500 + (123.060)(HS)(cos Θ/2) + (555,600)(sin Θ/2≤65,500 N (for guy)
10,500 + (123.060)(HS)(cos Θ/2) + (555,600)(sin Θ/2≤50,000 N (for anchor)
For the 2 OHGW:
2(27.920)(HS)(cos Θ/2) + 2(104,800)(sin Θ/2)≤ Gcos
55.840(HS)(cos Θ/2) + (209,600)(sin Θ/2)≤65,000 N (for guy)
55.840(HS)(cos Θ/2) + (209,600)(sin Θ/2)≤50,000 N (for anchor)

Case 2: Using 2 guy wires and 2 anchors for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:
10,500 + (123.060)(HS)(cos Θ/2) + (555,600)(sin Θ/2)≤2(65,500)N (for guy)
10,500 + (123.060)(HS)(cos Θ/2) + (555,600)(sin Θ/2)≤2(50,000)N (for anchor)
For the OHGW: (same as above)
(See Guying Guide for plot of controlling equation).

ENGLISH

e. General equation: $4(a+b)+2c = G\cos\phi$

For the conductor:

$$4[.7027(HS)(\cos \Theta/2) + 196 + 2[2(10{,}400)(\sin \Theta/2)] = G\cos\phi$$
$$785+(2.811)(HS)(\cos \Theta/2) + (41{,}600)(\sin \Theta/2) = G\cos\phi$$

For the OHGW:

$$4[.4783(HS)(\cos \Theta/2)+(neg.)] + 2[2(5{,}900)(\sin \Theta/2)] = G\cos\phi$$
$$(1.913)(HS)(\cos \Theta/2) + (23{,}600)(\sin \Theta/2) = G\cos\phi$$

Case 1: Using 1 guy wire and 1 anchor for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$3(785) + 3(2.811)(HS)(\cos \Theta/2) + 3(41{,}600)(\sin \Theta/2 \leq G\cos\phi$$
$$2355 + 8.433(HS)(\cos \Theta/2) + (124{,}800)(\sin \Theta/2) \leq 14{,}700 \text{ lbs.}$$
(for guy)
$$2355 + 8.433(HS)(\cos \Theta/2) + (124{,}800)(\sin \Theta/2) \leq 11{,}300 \text{ lbs.}$$
(for anchor)

For the 2 OHGW:

$$2(1.913)(HS)(\cos \Theta/2) + 2(23{,}600)(\sin \Theta/2) \leq G\cos\phi$$
$$3.826(HS)(\cos \Theta/2) + (47{,}200)(\sin \Theta/2) \leq 14{,}700 \text{ lbs.}$$
(for guy)
$$3.826(HS)(\cos \Theta/2) + (47{,}200)(\sin \Theta/2) \leq 11{,}300 \text{ lbs.}$$
(for anchor)

Case 2: Using 2 guy wires and 2 anchors for the three conductors and 1 guy wire and 1 anchor for both OHGW, the following general equations result (1/1 leads).

For the 3 conductors:

$$2355 + (8.433)(HS)(\cos \Theta/2) + (124{,}800)(\sin \Theta/2) \leq 2(14{,}700) \text{ lbs.}$$
(for guy)
$$2355 + (8.433)(HS)(\cos \Theta/2) + (124{,}800)(\sin \Theta/2) \leq 2(11{,}300) \text{ lbs.}$$
(for anchor)

For the OHGW: (same as above)

See Guying Guide on page 14-16 for plot of controlling equation.

f. Checking for buckling of the poles. Since the outside poles carry the maximum axial load, it is necessary only to examine this pole. Longitudinal buckling is considered since this condition is the critical case. Weight of the conductor and OHGW is included in the calculations.

Case 1: For the various heights of structures, the maximum axial load which various poles can sustain can be calculated. Method "b", section 14-5.3 is used to calculate P_{cr} below:

Pole Height	Unbraced length, ℓ Ground to lowest guy attach. m (ft)	$k\ell$ (k = 1.0) pinned-pinned	dia. @ 1/3 ℓ mm (in)	$P_{cr} = \frac{\pi^2 EI}{(k\ell)^2}$ N (lbs)
60-1	13.1 (43)	13.1 (43)	292 (11.5)	269,000 (60,500)
60-2			272 (10.7)	202,000 (45,300)
60-3			264 (10.4)	180,000 (40,500)
80-1	18.6 (61)	18.6 (61)	305 (12.0)	158,000 (35,600)
80-2			290 (11.4)	129,000 (29,000)
80-3			269 (10.6)	96,500 (21,700)
100-1	24.4 (80)	24.4 (80)	330 (13.0)	127,000 (28,500)
100-2			302 (11.9)	89,000 (20,000)

Assuming the horizontal spans are equal to the vertical span, the previous equations in "d" can be revised to include the weight of the conductor and OHGW on the outside pole. The total axial load in the pole is the sum of the axial loads induced in the pole from guying the three conductors and two OHGW and the vertical weight of the OHGW and the conductor. Half of the vertical load from the outside phase is carried by the middle pole and other half is carried by the outside pole. The vertical load is multiplied by an OCF of 2 in order to insure a safety factor of 2 against buckling. For this example, since the guy leads are 1 to 1, the vertical axial load from the guy wire will be equal to the horizontal component of the guy wire.

METRIC	2 x weight	+ 4a	+ 4b	+ 2c
Cond.	2(.5)(30.557)HS	+ 123.060(HS)(cos Θ/2)	+ 10,500	+ 555,600(sin Θ/2)
OHGW	2(14.308)HS	+ 55.840(HS)(cos Θ/2)	+	209,600(sin Θ/2)
	(59,174)HS	+ 178.90 (HS)(Cos Θ/2)	+ 10,500	+ 765,200(sin Θ/2) ≤ P_{cr}

ENGLISH				
Cond.	2(.5)(2.0938)HS	+ 8.433(HS)(cos Θ/2)	+ 2,355	+ 124,800(sin Θ/2)
OHGW	2(.9804)HS	+ 3.826(HS)(cos Θ/2)	+	47,200(sin Θ/2)
	(4.055)HS	+ 12.259(HS)(cos Θ/2)	+ 2,355	+ 172,000(sin Θ/2) ≤ P_{cr}

GUYING GUIDE

Structure TH-12 Ruling Span 244m (800 ft)

Conductor

Type 795 26/7 Max. Tension (L,M,H) 46,300(10,400) p_c 10.255(.7027)

w_c 30.557(2.0938)

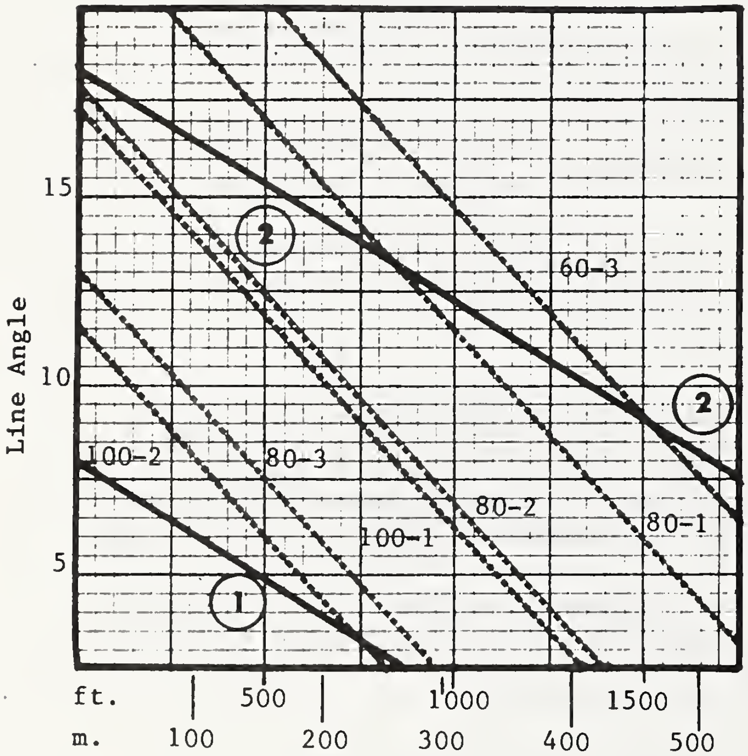
OHGW

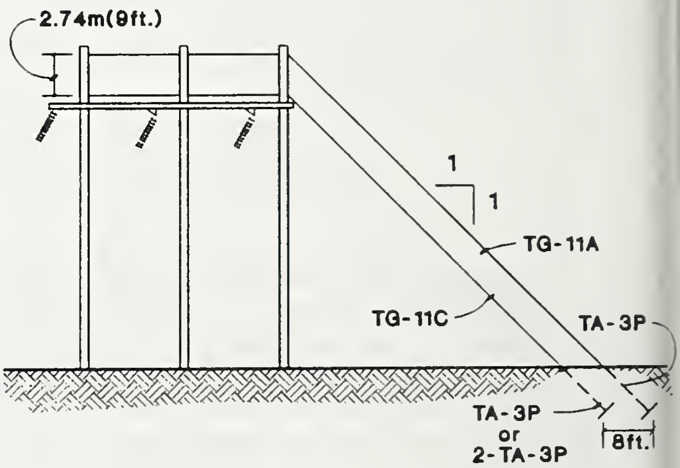
Type 7/16" E.H.S. Max. Tension (L,M,H) 26,200 (5,900) p_g 6.980(.4783)

w_g 14.308(.9804)

Guy Wire

Type 7/16"E.H.S. Ult. Strength 92,500(20.800)





Case 1
For OHGW: TG-11A, TA-3P
For cond: TG-11A, TA-3P

Total guys and anchors:
2-TG-11A
2-TA-3P

Limitation: TA-3P to cond.

Case 2
For OHGW: TG-11A, TA-3P
For cond: TG-11C, 2-TA-3P

Total guys and anchors:
1-TG-11A
1-TG-11C
3-TA-3P

Limitation: TA-3P to cond.

15. HARDWARE

15.1 General: Hardware for transmission lines can be separated into conductor related hardware and structure related hardware.

For many transmission lines, the conductor may constitute the most expensive single component of investment. Yet, this is the one component which is most exposed to danger and most easily damaged. In the design of any line, appropriate emphasis should be given to the mechanical and electrical demands on the design of conductor related hardware which will support, join, separate, reinforce, and mechanically damp overhead conductors. The selection and proper installation of conductor accessories will have considerable influence on the operation and maintenance of a transmission line. The electrical, mechanical, and material design considerations are generally involved in the design of conductor support hardware and conductor motion hardware.

Structure related hardware includes any hardware necessary to frame structures, to provide guying and pole attachments to the structure, and to provide necessary line to structure clearances. As connecting pieces for structural members, proper selection of hardware is necessary to assure structure strength. At the same time, proper selection of hardware to be static proof aids in reducing possible radio and television interference.

15.2 Conductor Related Hardware

15.2.1 Suspension Clamps: Contoured suspension clamps are designed to match the conductor diameter in order to guard against conductor ovalling and excessively high compressive stresses. Suspension clamps may be made from galvanized malleable iron or forged steel with appropriate aluminum liners (not recommended for copper conductors) or copper liners. The connector fitting will usually be either a socket or clevis (see Figure 15-1). When armor rods and liners are used, proper selection of the seating diameter of the clamps should be made. Liners can be expected to add 2.54 mm (.1 in.) to the conductor diameter. There are a few clamps made for large angles (up to 120°). However, these clamps are available only for small conductor sizes. When angles are encountered on a transmission line using large conductors, strain clamps should be used, or in the case of medium angles, double suspension clamps connected to a yoke plate may be needed to make a gradual turn.

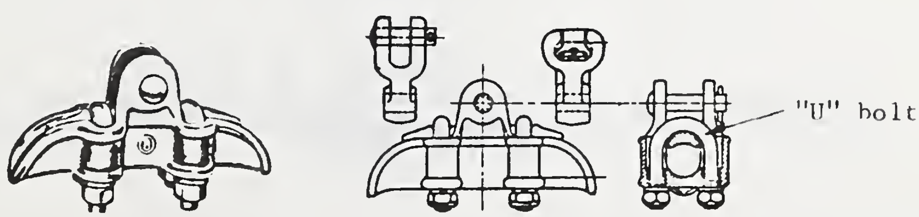


FIGURE 15-1: SUSPENSION CLAMP WITH CLEVIS OR BALL AND SOCKET TYPE OF CONNECTION. ("U" bolts insure permanent conductor-to-clamp contact and prevents burning of the conductor).

Cushioned suspension clamps are sometimes used to support the conductor and to reduce to static and bending stresses in the conductor. Cushioned suspension units are further explained in the conductor motion hardware section.

15.2.2 Clamp Top Clamps: Clamp top clamps for vertical and horizontal post insulators are popular because of their simplicity of installation. The clamps, either made of malleable iron or aluminum alloy, are mounted on a metal cap. The clamp itself is composed of a removable trunion capscrew (keeper piece) and a trunion saddle piece. Straight line clamps are designed to hold conductors without damage on tangent and line angles of up to approximately 15°. The maximum acceptable vertical angle (each side of clamp) is usually taken to be approximately 15° with the horizontal. Since the keeper piece of the clamp is not designed to provide the support for upward loading, uplift conditions should be avoided. There are angle clamps available which are designed to take up to a 60° line angle. However, when line angles are greater than 15° to 20°, suspension insulators are usually recommended.

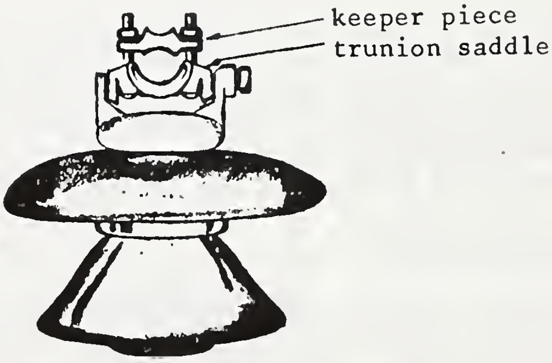


FIGURE 15-2: PIN TYPE INSULATOR WITH CLAMP TOP CLAMP.

15.2.3 Tied Supports: A large portion of lower voltage construction involves tying of conductors to pin and post insulator supports. Hand ties are occasionally vulnerable to loosening from various forces and motion from differential ice buildup, ice dropping, galloping, and vibration. Factory formed ties with the characteristics of a secure fit, low stress concentration, and uniformity of installation, may eliminate mechanical difficulties and radio interference problems associated with loose tie wires.

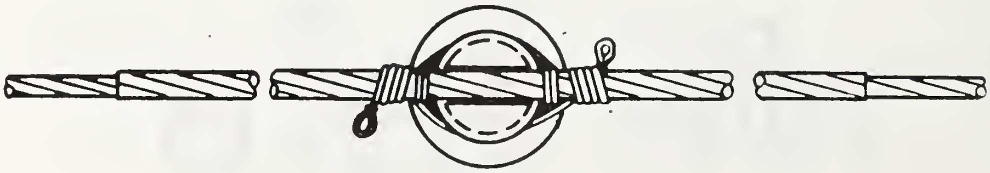


FIGURE 15-3: TOP GROOVE TIE, ACSR CONDUCTOR WITH STRAIGHT OR PREFORMED ARMOR RODS.

15.2.4 Deadend Clamps: Deadending a conductor may be accomplished using formed type deadends, automatic deadends, bolted or compression type deadends. Because of the strength limitations of the formed and automatic deadends, these types are limited to primarily small conductor sizes and distribution use. The two basic methods of deadending a transmission conductor are by the use of bolted or compression type deadend clamps.

Deadend clamps or strain clamps, as they are sometimes called, are made from three basic types of material as follows:

(a) Aluminum Alloy Type (most prevalent)

General notes: Corrosion resistant, minimizes power losses, minimizes hysteresis and eddy currents, minimizes excessive conductor heating in the conductor clamping area, lightweight.
Application: No armor rods or tape required. Use with ACSR or all aluminum conductors. Clamps are not to be used with copper or copperclad conductors.

(b) Malleable Iron

General notes: Somewhat lightweight, range of conductor sizes limited.
Application: Must use aluminum or copper liners.
May be used with copperclad, ACSR, and other composite conductors.

(c) Forged Steel

General notes: Heavy in weight.
Application: Use liners of the same material as the conductor.
May be used for all aluminum, copper or ACSR conductors.

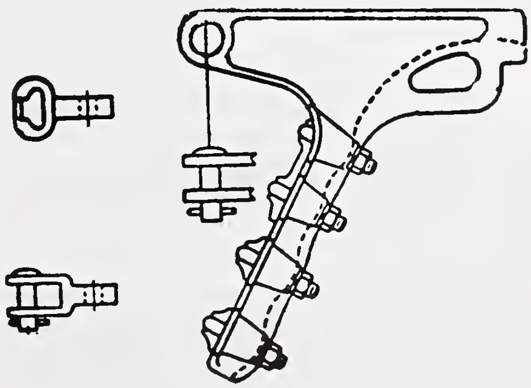


FIGURE 15-4a: TYPICAL BOLTED DEADEND CLAMP

A compression type deadend is depicted below:

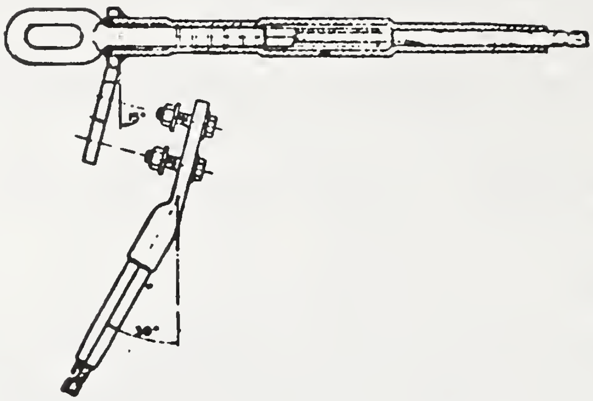


FIGURE 15-4b: TYPICAL COMPRESSION DEADEND

The ultimate strength of the body of the bolted clamps should meet or exceed the ultimate strength of the conductor. The holding power of the bolted type or compression type clamp must meet the following criteria: (a) Clamps shall hold 90 percent of the strength of the largest conductor in a short-time load; (b) Clamps must hold a sustained load of 75 percent of the strength of the conductor for 3 days. For bolted type clamps, bolts should be tightened to 400 in./lbs. of torque. Clamps and splices should also meet certain corrosion resistance tests and heat cycling tests.

For high voltage, suspension and deadend clamps are designed to control corona by smoothing and rounding all edges and by placing within the electrical shielding of the clamp body all nuts and studs that present sharp edges.

15.2.5 <u>Splices</u>: Conductor splices may be formed utilizing automatic compression type splices, formed type, or crimp compression type splices. For most transmission conductors, the crimped compression type splice is used because of its high strength capabilities. Splices should meet the same strength, corrosion resistance, and heat cycling requirements as the deadend clamps.

15.2.6 <u>Strain Yokes</u>: Two or more insulator strings may be connected in parallel by using yokes in order to: sustain heavy loads; increase the safety factor for long-span river crossings; make a gradual turn at large angles; and to deadend. Usually, it is more economical to supply higher strength rating insulators than using yokes.

15.2.7 <u>Insulators</u>: The mechanical and electrical requirements of insulators are discussed in Chapter 8. Where suspension insulators are exposed to salt sprays or corrosive industrial emissions, insulators using enlarged pin shafts or corrosion intercepting sleeves (CIS) prolong the life of the insulator pin. The "CIS" leaves an air space between the pin and the cement. The corrosion will attack the long-lived but expendable sleeve and any volumetric increase at the rust line will distort the sleeve without imposing bursting stresses on the adjacent porcelain. Other types of insulators have an enlarged shaft near the cement line which provides additional sacrificial metal for corrosion.

FIGURE 15-5: SUSPENSION INSULATORS - BALL AND SOCKET TYPE (LEFT) AND CLEVIS-EYE TYPE (RIGHT).

For lower voltages, pin and post type insulators are mounted on structure crossarms. The side and top wire groove generally limits the size of the conductor with armor rod to a maximum of 4/0 and 336.4 kcmil ACSR.

15.2.8 Fittings: There are a variety of fittings used to attach the insulator to the structure. These may include hooks, "Y" ball/clevis, ball eyes, ball clevises and chain, anchor or vee shackles. The "C" hooks suggested on REA construction are the self locking hooks. With the insulator cap in place, the opening of the hook is sufficiently restricted so that accidental disconnection cannot occur. Fittings should meet or exceed the M&E ratings of the insulators. The various fitting types are shown below.

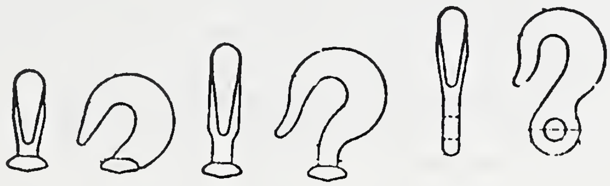


FIGURE 15-6: DIFFERENT TYPES OF HOOKS. SELF LOCKING "C" HOOK (LEFT); BALL HOOK (MIDDLE); CLEVIS TYPE HOOK (RIGHT).

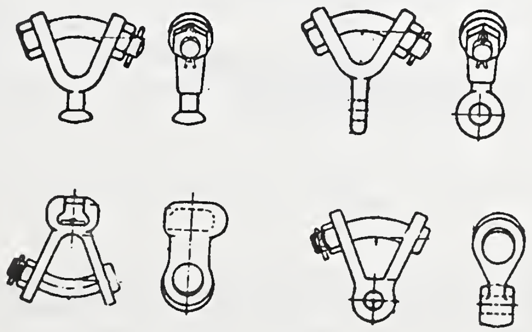


FIGURE 15-7: VARIOUS TYPES OF BALL AND CLEVIS "Y" CONNECTIONS.

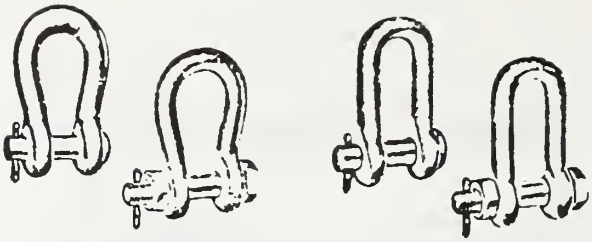


FIGURE 15-8: ANCHOR SHACKLE (LEFT); CHAIN SHACKLE (RIGHT).

15.3 Conductor Motion Hardware:

15.3.1 Aeolian Vibration: There are several methods to reduce the effects that aeolian vibration has on lines. The selection of the proper hardware to improve conductor life will depend on the degree of vibration. All conductors are in some state of vibration, varying from extremely slight to temporarily severe. Suspension clamps do not restrict vibration, but the design of suspension clamps should keep to a minimum the effect of such vibration on the conductor.

Armor Rods should be used on lines in areas where mild vibrations may occur. Armor rods, wrenched or preformed, are helical layers of round rods which are installed over the conductor at the points of attachment to the supporting structures. The primary purpose of armor rods is to provide additional rigidity to the conductor at its point of support. The use of armor rods accomplishes several things: (a) the armor rods provide a gentler slope of curvature for the incoming conductor and hence alleviates the changes of mechanical stress buildup at the point of support; (b) by increasing the flexural rigidity of the conductor, bending stresses are reduced in the conductor, thereby increasing its fatigue life; (c) the conductor is protected from flashover damage and mechanical wear at the points of support.

In laboratory tests, the placement of armor rods on the conductor has shown that the conductor is able to withstand considerably more vibration cycles without fatigue failure. Tests such as these show that there is a significant reduction in stress afforded through the use of armor rods.

FIGURE 15-9: ARMOR RODS USED WITH SUSPENSION INSULATORS.

Cushioned Suspension units use the concept of a resilient cushioning in conjunction with armor rods to further reduce the static and dynamic bending stresses in the conductor. The compressive clamping force is decreased, thereby reducing stress concentration notches and the degree of fitting. For line angles greater than 30°, single support units should be replaced with

double units. When considering longitudinal loads for a line using cushioned suspension units, the designer should consider that the units have a slip load of approximately 20 percent of the rated breaking strength of the conductor.

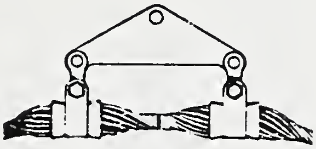


FIGURE 15-10:
CUSHIONED SUSPENSION UNIT

FIGURE 15-11:
DOUBLE CUSHIONED SUSPENSION
FOR LINE ANGLES GREATER THAN 30°

Dampers are used in areas of severe vibration in order to attenuate aeolian vibration amplitudes, thereby reducing the dynamic bending stress at hardware locations and extending conductor life. Most of the present suspension dampers make use of the connecting cables between weights to dissipate the energy supplied to the damper. The other type of vibration damper is the spiral damper which is limited to small conductor sizes (Figure 15-13).

When a vibration wave passes the damper location, the clamp of the suspension type damper oscillates up and down, causing flexure of the damper cable and creating a relative motion between the damper clamp and damper weights. The stored energy from the vibration wave is dissipated to the damper in the form of heat. For a damper to be effective, its response characteristics should be consistent with the frequencies of the conductor on which it is installed. Dampers of various designs are available from a number of manufacturers. The number of dampers required, as well as their location in the span should be determined by the damper manufacturer.

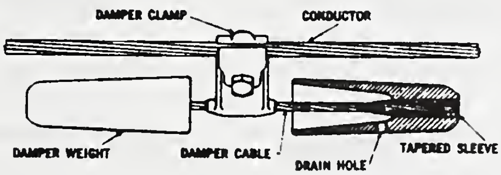


FIGURE 15-12: TYPICAL DAMPER

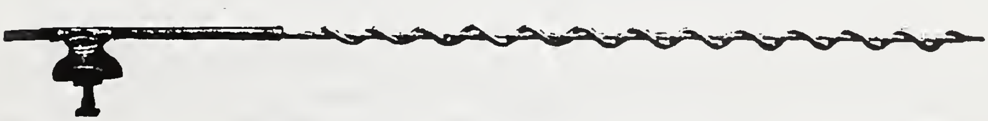


FIGURE 15-13: SPIRAL VIBRATION DAMPER FOR SMALL CONDUCTORS.

Application of armor rods, cushion suspension and dampers or a combination thereof should be on a case-by-case basis. A certain item should not be used merely because it has given satisfactory performance in another location.

If the prevailing wind conditions and the terrain are such that the vibration will occur most of the time, then some form of vibration protection should be investigated. Dampers should be selected on the basis of the frequencies one expects to encounter in the terrain that must be traversed. The engineer should not specify a certain type of damper or armor rod simply because everyone else is using them. An improperly located damper can affect the amount of protection and ability of the damper to suppress the damaging effects of aeolian vibration.

Armor rods are meant to be reinforcement items and not dampers. Because of this, vibrations are passed on through the conductor clamp basically without any attenuation, and then are dissipated in the supporting structure. If the structure is made of steel and if fatigue should become a problem, then the use of dampers along with armor rods should be investigated. However, care should be exercised in selecting the distance between the ends of the armor rods and the dampers, if both are to be used.

15.3.2 Galloping: The hazards associated with galloping conductors are contact between phases or between phase conductors and ground wires, racking of the structure, and possible mechanical damage at supports. Aerodynamic drag dampers and interphase spacers are two types of hardware used to limit the amplitude of the conductor during galloping. The historical effectiveness of antigalloping devices has been sporadic.

15.3.3 Bundled Conductors: Bundled conductors are not used very often on transmission lines under 230 kV but are often economically justified above 230 kV. Bundled conductors can experience aeolian vibration, galloping, corona vibration, and subconductor oscillation. For a bundled conductor with spacers, aeolian vibration may be reduced by a factor of 10. However, galloping of ice coated conductors will occur more readily and more severely on bundled lines than on single conductors in the same environment. Subconductor oscillation, though, has caused the major share of the problems to date. It is caused by one conductor lying in the wake of an upstream conductor and thereby being excited in nearly a horizontal ellipse. Damage has consisted of conductor wear and spacer deterioration and breakage. In order to reduce subconductor oscillation, subspan length or the distance between spacers should be kept below 250 feet.

There are a number of different types of spacers and spacer dampers. The primary purpose of spacers is to reduce the probability of conductor contact and magnitude of vibration. Spacers may be rigid, articulated or flexible, open-coil and closed-coil springs, and wire rope and steel strand connecting members. Spacers should grip the conductor securely to avoid abrasion of the subconductors and to prevent conductor entanglement during strong winds.

15.3.4 Insulator Swing: Occasionally, tie down weights are used to control conductor position by preventing excessive uplift and swinging. A line should not be designed to use tie down weights as a means of preventing the conductor from swinging into the structure, but sometimes due to a low V/H span ratio,

weights may have to be used on an occasional structure. Two types are shown below in Figure 15-14.

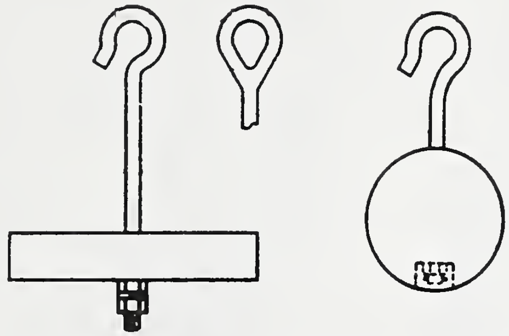


FIGURE 15-14: DISC WEIGHTS (LEFT); BALL WEIGHTS (RIGHT)

15.4 Structure Related Hardware:

15.4.1 Fasteners: The threaded rod and machine bolt are frequently used with wood transmission structures. Static proof bolts have a washer securely fixed to the head of the bolt and are furnished with washer nuts. Modifications to these bolts include shoulder eye bolts with round or curved washers welded to the eye, forged shoulder eye bolts and forged eye bolts. M-F type locknuts, used in conjunction with a regular nut or washer nut, form a solid unit which does not loosen from vibration and helps to maintain a static proof installation. The strengths and tensile stress areas of bolts conforming to ANSI C135.1 are given in Appendix H.

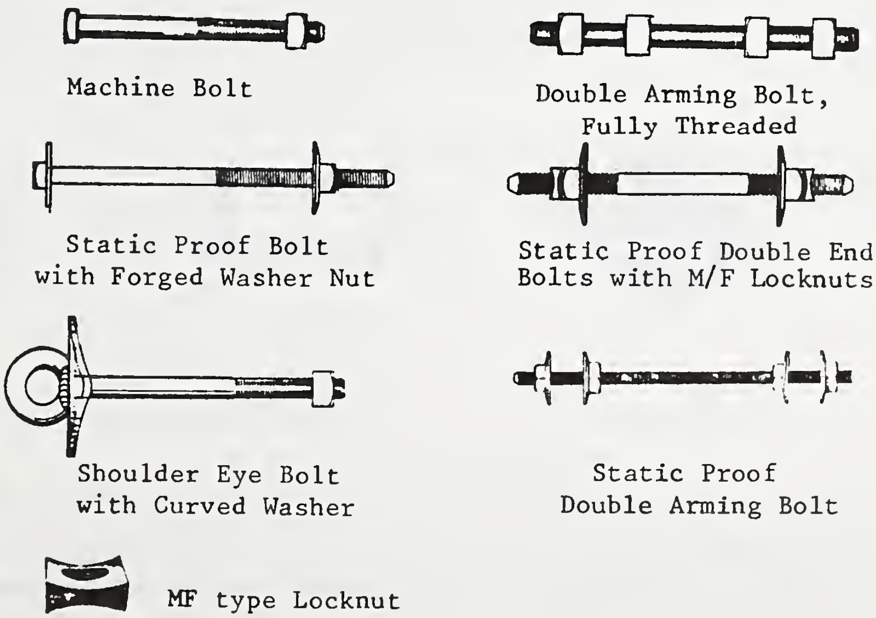


FIGURE 15-15: FASTENERS

TABLE 15-1
Strengths for Machine Bolts, Double Arming Bolts, Double End Bolts, Conforming to ANSI C135.1

Machine Bolt Diameter		Tensile Stress Area		Min. Tensile Strength	
mm	(in.)	mm^2	(in^2)	N	(lbs.)
12.7	(1/2")	91.5	(.142)	34,700	(7,800)
15.8	(5/8")	145.8	(.226)	55,200	(12,400)
19.0	(3/4")	215.5	(.334)	81,600	(18,350)
22.2	(7/8")	298.1	(.462)	112,900	(25,400)
25.4	(1")	391.0	(.606)	149,000	(33,500)

Lag screws are sometimes used in lieu of bolts when shear loads are small. A lag screw with fettered edges is driven into the wood and maintains its holding power by the cone shaped threads. When used, the moment capacity of the pole is reduced in the same manner as a bolt hole reduces moment capacity.

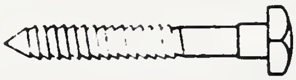
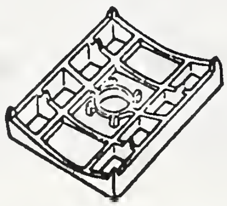


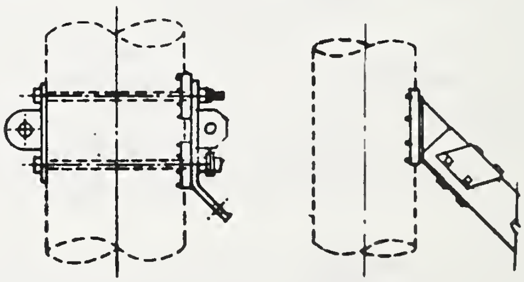
FIGURE 15-16: LAG SCREW

Anti-split bolts help prevent the propagation of checking and splitting at the end of crossarms. A three inch edge distance should be provided between the anti-split bolt and the edge of the arm.

15.4.2 Framing Fittings: The primary purpose for using grid gains is to reduce bolt hole slotting by distributing the shear load of the bolt over a large wood area. The special shaped teeth of the grid gain press into the wood surface and offer maximum resistance to movement both with and across the grain of the wood. The use of grid gains will strengthen bolt connections and are recommended anytime the bolt must carry a substantial shear load.



Grid Gain

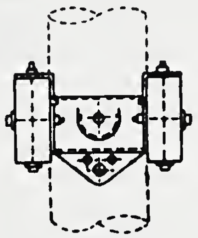


Application of Grid Gains

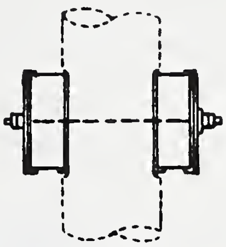
FIGURE 15-17: GRID GAINS

The gain plate between the pole and the crossarm and the reinforcing plate on the outside of the arm provide additional metal bearing surface in order to transfer the vertical load from the crossarm to the bolt. The gain plate eliminates the decay area between two wood contact areas. The reinforcing plate, also called a ribbed tie plate, will prevent the crossarm from

When double crossarms are used to increase vertical spans or longitudinal strength capabilities, spacer fittings are needed to separate the crossarms and to provide a point of attachment for suspension insulators. If fixed spacers are used, poles should be gained. Since the standard fixed spacing sizes are 7-1/2", 9", 10-1/2", and 12", the crossarm may be bowed ±1/2". The brand on the butt and face of the pole should include proper designation of the fixed spacer size. Adjustable spacers will fit a range of pole diameters and as such the pole need not be gained.



Spacer Fitting



Reinforcing Plate and Gain Plate

FIGURE 15-18

15.4.3 <u>Swing Angle Brackets</u>: In order to increase clearance between phase conductors and the structure, swing brackets are mounted horizontally or vertically. The two primary types of angle brackets are the rod type for light loads, and the angle iron type for heavier loads.

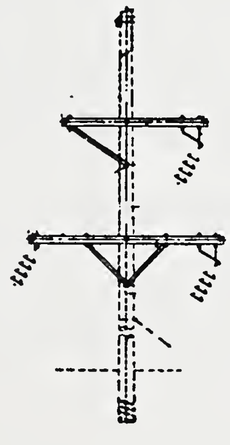


FIGURE 15-19: SMALL ANGLE STRUCTURE WITH SWING ANGLE BRACKETS.

15.5 <u>Guy attachments:</u> The primary types of guy attachments used on transmission lines include the wrap guy, guying plates, pole eye plates, guying tees, and pole bands. Other types of guy attachments such as formed straps, angle bolt eyes, and goat hooks are used primarily on distribution lines. "Guy" attachments are used to attach the insulators to the structure as well as providing a means of guying the structure.

15.6 Corrosion of Hardware: Corrosion may be defined as the destruction of a metal by a chemical or electro-chemical reaction with its environment. Certain industrial and sea coast environments accelerate the rate of corrosion. Parameters which stimulate corrosion include air (oxygen) dissolved in water, airborne acids, sulphur compounds (from cinders, coke, coal dust), salt dissolved in water, corona, etc.

Any two dissimilar metals when placed together in the presence of an electrolyte form a simple battery. One metal becomes an anode, sacrificing itself to the other metal (cathode). One method to reduce the rate of corrosion is to select metals which are compatible with one another. For the table below, the greater the algebraic difference between metals, the more rapid the rate of corrosion of the electronegative element.

Silver	+ .79
Copper	+ .34
Lead	- .13
Tin	- .15
Iron	- .35
Chromium	- .47
Zinc	- .77
Aluminum	-1.337

As an example, when malleable iron suspension clamps are used, aluminum liners should be furnished in order to reduce the rate of corrosion of the aluminum conductor. As in another example, the selection of staples to be used on the pole ground wire must be a compatible material to the ground wire (see Drawing TM-9).

Other methods of reducing the rate of corrosion are to increase metal thickness, galvanize, tin plate, paint or cover with corrosion inhibitors.

16. UNDERBUILD

16.1 General: The placing of underbuild distribution or communication circuits on transmission lines is a practice that is becoming more prevalent as demands on rights-of-way increase. Although underbuild distribution lines increase the initial cost of a transmission line, a common sharing of a right-of-way is sometimes necessary in order to build the line.

16.2 Addition of Distribution Underbuild to an Existing Transmission Line: Distribution circuits should not be added to existing transmission structures unless the structures were originally designed for underbuild.

16.3 Strength Requirements: Standard distribution construction is required to meet NESC Grade C construction in accordance with 7 CFR Part 1724. However, underbuild distribution on transmission circuits, with the exception of the crossarms, should be built to meet all requirements of REA Grade B construction. This means that the loading on the pole due to the distribution circuits must be calculated using an overload capacity factor for four, and all guying for the underbuild must meet the guying requirements for transmission. Distribution crossarms on transmission structures need to meet Grade C construction.

16.4 Line-to-Ground Clearances: Since the closest conductor to ground will usually be that of the distribution circuits, the clearances to ground and clearances in crossing situations will most probably be controlled by the limits set up for the distribution circuits.

The problem of providing satisfactory clearance becomes more involved when crossing other utility circuits. In these instances, very careful attention should be given to the allowable clearance in Section 23 of the NESC.

Particular attention should be given to the use of reduced size distribution neutrals since the clearance to ground for the neutral, by virtue of its increased sag and position on the pole or crossarm, may be the controlling factor for pole height. In some cases, it may be more economical to increase the size of the neutral so as to reduce its sag.

16.5 Separation Between Transmission and Underbuild Distribution Circuits: The clearances given in this section are intended to provide not only operating clearances but also sufficient working clearances. A line worker must be able to work on the underbuild without getting into the space occupied by the transmission conductors.

16.5.1 Horizontal Separation: The horizontal separation at the support between the lowest transmission conductor(s) and the highest distribution conductor(s) or neutral should be at least .3 meter (1 foot) if possible as illustrated in Figure 16-1.

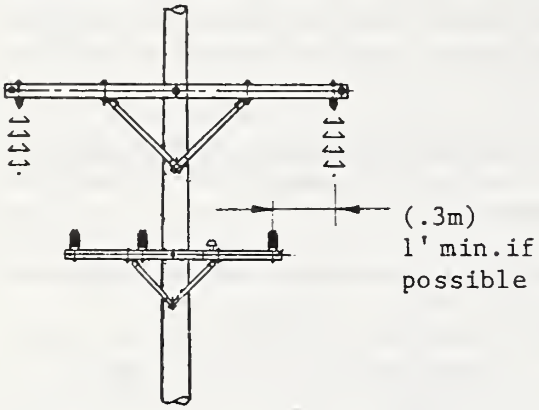


FIGURE 16-1: HORIZONTAL SEPARATION REQUIREMENTS BETWEEN TRANSMISSION AND UNDERBUILD

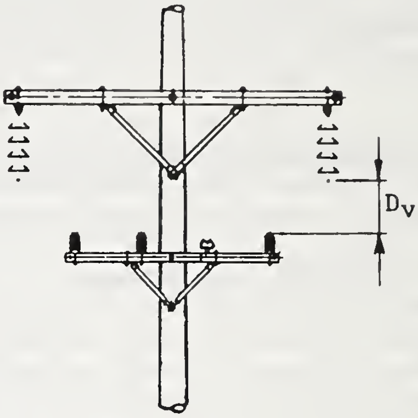


FIGURE 16-2: VERTICAL SEPRATION REQUIREMENTS AT STRUCTURE, FOR UNDERBUILD

16.5.2 Vertical Clearance to Underbuild at Supports: The recommended minimum vertical clearances between the transmission conductors and the underbuild conductors at the support are given in Table 16-1. These clearances apply regardless of the amount of horizontal separation between transmission and underbuild conductors (see Figure 16-2).

16.5.3 Vertical Clearance to Underbuild at any Point in the Span: The recommended minimum vertical clearances at any point along the span are given in Table 16-1.

The clearances apply for an upper conductor at final sag for the condition below yielding the greatest sag for the line.

(a) A conductor temperature of 0°C (32°F), no wind, with the radial thickness of ice for the applicable loading district;

(b) A conductor temperature of 75°C (167°F);

(c) Maximum design conductor temperature, no wind, under emergency loading conditions. For high voltage bulk transmission lines of major importance to the system, consideration should be given to the use of 100°C (212°F) as the maximum design conductor temperature.

The sag of the underbuild conductor to be used is the final sag, at 16°C (60°F), no wind.

If the altitude of the transmission line or portion thereof is greater than 1000 meters (3300 feet), an additional clearance as indicated in Table 16-1 must be added to both category 1 and 2 clearances (clearance at the structure and at the midspan point) given.

TABLE 16-1

RECOMMENDED MINIMUM VERTICAL CLEARANCES TO DISTRIBUTION OR COMMUNICATION UNDERBUILD ON TRANSMISSION LINES IN METERS (FEET) (CIRCUITS MAY BE OF THE SAME OR DIFFERENT UTILITIES)

CLEARANCES BETWEEN TRANSMISSION AND DISTRIBUTION CONDUCTORS:	Nominal Line-to-Line Voltage in kV 34.5-46	69	115	138	161	230
1. Clearance from point of suspension of transmission conductor to point of suspension of underbuild distribution or communication conductor. Nominal underbuild voltage in kV line-to-line:						
a. 25 kV and below (including communication conductors)	1.6 (5)	1.6 (5.4)	1.9 (6.3)	2.1 (6.8)	2.2 (7.3)	2.7 (8.7)
b. 34.5 kV	1.6 (5)	1.7 (5.5)	2.0 (6.5)	2.1 (7.0)	2.3 (7.5)	2.8 (9.0)
2. Clearance at any point in span from transmission conductor to underbuild conductor. Nominal underbuild voltage in kV line-to-line:						
a. 25 kV and below (including communication conductors	1.2 (4.3)	1.3 (4.6)	1.5 (5.4)	1.7 (5.7)	1.8 (6.1)	2.3 (7.1)
b. 34.5 kV	1.2 (4.4)	1.3 (4.8)	1.6 (5.5)	1.7 (5.9)	1.9 (6.2)	2.3 (7.3)
ALTITUDE CORRECTION TO BE ADDED TO VALUES ABOVE:						
Additional meters of clearance per 300 meters of altitude above 1000 meters (additional feet of clearance per 1000 feet of altitude above 3300 feet).	0 (0)	.01 (.02)	.016 (.05)	.02 (.07)	.025 (.08)	.04 (.12)

16.5.4 <u>Additional Clearance Requirements for Communication Underbuild</u>: For communication underbuild, the low point of the transmission conductors at final sag, 16°C (60°F), no wind, should not be lower than a straight line joining the points of support of the highest communication underbuild.

16.5.5 <u>Span Length and Clearance to Underbuild</u>: The conditions of either 16.5.2 or 16.5.3 above will dictate what the minimum clearance to underbuild at the structure should be. If the clearance to underbuild at the support as dictated by 16.5.2 above results in a clearance at midspan inadequate to meet the requirements of 16.5.3, the clearance at the structure would have to be increased. Since the vertical separation at the structure may depend upon the relative sags of transmission and underbuild conductors, and since the span length has an effect on relative sags, the resulting minimum span as limited by vertical clearance to underbuild should be calculated to insure that for each span the vertical separation at the support is correct.

The formula for maximum span as limited by clearance to underbuild is:

$$L_{max} = (RS)\sqrt{\frac{A - B}{S_\ell - S_u}} \qquad \text{Eq. 16-1}$$

where:
Lmax = maximum span in meters (feet).
RS = the ruling span in meters (feet).
A = the allowable separation at midspan in meters (feet).
B = the vertical separation at supports in meters (feet).
S_ℓ = the underbuild sag at 16°C (60°F), final, in meters (feet).
S_u = the transmission conductor sag at worst case condition, final sag, in meters (feet).

16.6 <u>Climbing Space</u>: Climbing space through lower circuits should be preserved on one side of the pole or in one quadrant from the ground to the top of the pole as required by the NESC. Working space should be provided in the vicinity of crossarms. Jumpers should be kept short enough to prevent their being displaced into the climbing space.

16.7 <u>Overhead Ground Wires and Distribution Neutrals</u>: Distribution underbuild should have its own neutral. This neutral may be tied to the transmission pole ground wire in order to improve its grounding. Depending on the characteristic of the circuits, a common ground or a separate ground is acceptable. If separate grounds are used, the pole ground wires should be located on opposite sides of the pole. In cases of separate grounds, similar materials should be used for the transmission pole ground wire as well as the distribution pole ground and ground rod. For example, if copper is used for the transmission pole ground, then copper and/or copperclad should be used for the distribution ground rod and pole ground wire. Use of similar materials will reduce the possibility of galvanic corrosion. Likewise, the distribution anchors and transmission anchors should be of similar material as the ground rods and wire used for the pole butt wraps.

16.8 Additional Poles for Underbuild: There may be structures where it is either desirable or necessary to transfer distribution circuits to separate poles. The situations are:

- o Large Line Angles
- o Deadends
- o Tap-offs
- o Sectionalizing Structures
- o Substation Approaches
- o Transformers or Regulators
- o Capacitors

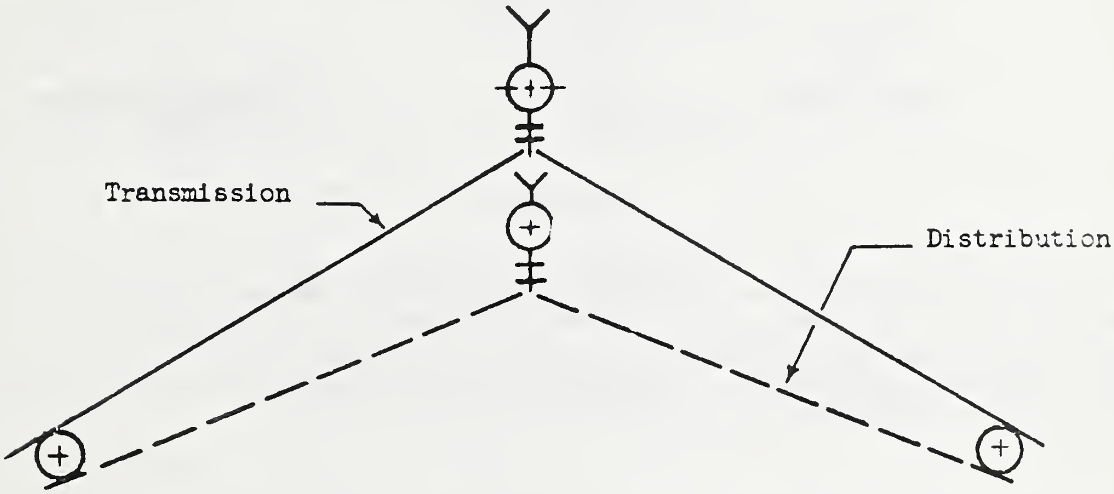


FIGURE 16-3: THE TRANSFERENCE OF THE DISTRIBUTION CIRCUIT TO A SEPARATE POLE AT A LARGE ANGLE.

The location of transformers on structures carrying both transmission and distribution lines should be avoided. Not only does the transformer create an unbalanced load on the structure,but the additional circuits necessary for service drops may become extremely hazardous to operating personnel.

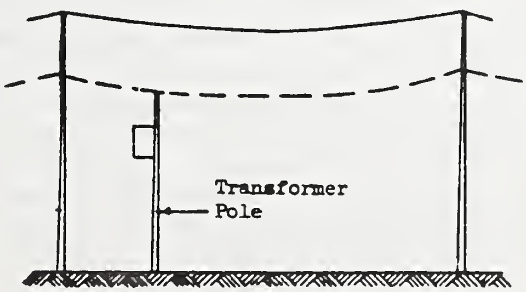


FIGURE 16-4: THE USE OF A SEPARATE POLE TO MOUNT A DISTRIBUTION TRANSFORMER.

16.9 Guying: The necessity for providing additional guys to compensate for the effect of underbuild on structures is readily apparent. However, there are locations in the line where special attention must be given to the guying being proposed. One example is a common use pole with a line tap.

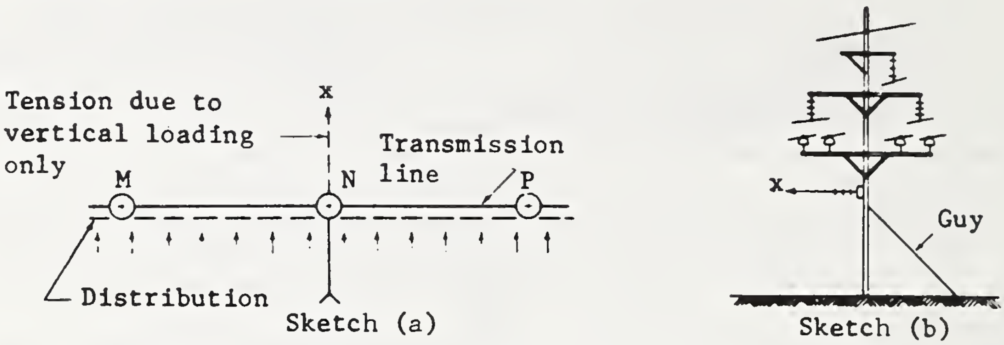


FIGURE 16-5

For winds perpendicular to the transmission line the guying as provided on Sketch (b) for the example shown on Sketch (a) may be insufficient if consideration has been given only to underbuild deadend tension shown as force (x). The maximum transverse load acts on one-half the sum of adjacent spans, $\frac{(MN + NP)}{2}$, of the transmission and distribution circuits.

These forces must be added to the tensions due to vertical loadings of tap conductors in order to determine the proper amount of guying required. Guying must meet Grade B construction. If winds are parallel to the transmission line, the deadend loading of the tap is larger and should be used.

It is also necessary to avoid exceeding the pole's fiber stress rating due to bending moment at the point of guy attachment.

Deadending of distribution circuits may require guying to the crossarm. Longitudinal guying must consider any unbalanced tensions in the transmission line conductors which ordinarily would deflect insulators or the pole top.

A general rule which can be applied is to consider that wherever, for any reason, the transmission circuit or the distribution circuit requires guys, both circuits should be guyed, and the guys should be so designed that the entire transverse load on the structure at maximum loading conditions shall be carried by guys and anchors. All drawings should show location and slope of guys to assure adequate clearances when guys are required. Positions of guys should be clear from other hardware or electrical connections, such as connectors between neutral and pole ground wire. Where guys may pass close to conductors, minimum clearances in accordance with Table 4-2 should be met.

16.10 Example: Maximum Span as Limited by Clearance to Underbuild: A 69 kV single pole transmission is to be built with a 25 kV underbuild distribution circuit. Determine maximum span as limited by clearance between transmission conductors and underbuild.

16.10.1 Given

a. Vertical separation between transmission and distribution conductors at structure: 2.13 m (7.0 ft.).

b. RS: 91 m (300 ft.).

c. Conductor sags in m (ft.).

Transmission Conductor
477 kcmil 26/7 ACSR

	initial	final
16°C (60°F)	.98 (3.22)	1.20 (3.91)
0°C (32°F) 12.7mm(1/2")ice	1.27 (4.17)	1.34 (4.40)
75°C (167°F)	1.77 (5.81)	1.98 (6.49)

Distribution Conductor
4/0 26/7 ACSR

	initial	final
16°C (60°F)	.63 (2.06)	.93 (3.03)

16.10.2 Solution

From Table 16-1 the required vertical clearance at midspan between the transmission and distribution conductors is 1.3 m (4.0 ft.).

The worst case sag for the transmission conductor is at 75°C (167°F) at final sag condition which is 1.98 m (6.49 ft.), and the sag value to be used for the distribution conductor is .93 m (3.03 ft.).

$$L_{max} = (RS)\sqrt{\frac{A - B}{S_\ell - S_u}} \qquad \text{Eq. 16-1}$$

Substituting: RS = 91 (300)
A = 1.3 (4)
B = 2.13 (7)
S_ℓ = .92 (3.03)
S_u = 1.98 (6.49)

$$L_{max} = (91)\sqrt{\frac{1.3 - 2.13}{.92 - 1.98}} \qquad \text{Eq. 16-1}$$

$$L_{max} = 81 \text{ m}$$

$$L_{max} = (300)\sqrt{\frac{4 - 7}{3.03 - 6.49}}$$

$$L_{max} = 279 \text{ ft.}$$

The maximum span is limited by separation between transmission and underbuild distribution is 81 m (279 ft.). The slight difference between the absolute distances represented by the metric and English values is due to the rounding of the metric clearance requirements.

APPENDIX A

TRANSMISSION LINE DESIGN DATA SUMMARY SHEET AND SUPPORTING INFORMATION

NOTES

TRANSMISSION LINE DESIGN DATA SUMMARY

I. GENERAL INFORMATION

BORROWER			DATE
LINE IDENTIFICATION			
VOLTAGE		LENGTH *(Miles)*	
TRANSMISSION ______ kV	UNDERBUILD ______ kV	TRANSMISSION ______ Mi	UNDERBUILD ______ Mi
TYPE OF TANGENT STRUCTURE		BASE POLE ______ Ht ______ Cl	
DESIGNED BY			

II. CONDUCTOR DATA

	TRANSMISSION	OHGW	UNDERBUILD	COMMON NEUTRAL
SIZE *(kcmil or IN.)*				
STRANDING				
MATERIAL				
DIAMETER *(IN.)*				
WEIGHT *(LB/FT.)*				
RATED STRENGTH *(LBS)*				

III. DESIGN LOADS

		TRANSMISSION *(LBS/FT)*	OHGW *(LBS/FT)*	UNDERBUILD *(LBS/FT)*	COMM. NEUTRAL *(LBS/FT)*
NESC: ______ LDG. DISTRICT					
a. ICE: ______ IN	Vertical				
b. WIND ON ICED CONDUCTOR ______ PSF	Transverse				
c. CONSTANT K: ______	Resultant + K				
HEAVY ICE *(NO WIND)* ______ IN	Vertical				
HIGH WIND *(NO ICE)* ______ PSF	Transverse				
OTHER					

IV. SAG & TENSION DATA

SPANS AVERAGE *(EST.)* ______ FT. MAXIMUM *(EST.)* ______ FT. RULING *(EST.)* ______ FT.

SOURCE OF SAG–TENSION DATA:	TRANSMISSION		OHGW		UNDERBUILD		COMMON NEUTRAL	
TENSIONS *(% RATED STRENGTH)*	Initial	Final	Initial	Final	Initial	Final	Initial	Final
NESC:								
a. UNLOADED (0° 15° 30°) ______ °F								
b. LOADED (0° 15° 30°) ______ °F								
MAXIMUM ICE 32°F								
HIGH WIND *(NO ICE)* ______ °F								
UNLOADED LOW TEMPERATURE ______ °F								
SAGS *(FT)*								
NESC DISTRICT LOADED ______ °F								
UNLOADED HIGH TEMP. *(120° FOR OHGW & U.B.)* ______ °F								
MAXIMUM ICE 32°F								
LOADED ½" ICE, NO WIND 32°F								

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT:

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADD. ALLOW. FOR TEMPLATE
TRANSMISSION						
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH: ______ FT. *(MIN.)* ______ FT. *(MAX.)*

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING:

HISTORY OF AEOLIAN VIBRATION:

a. TYPE OF VIBRATION DAMPERS USED *(IF ANY)*:

b. TYPE OF ARMOR RODS USED *(IF ANY)*:

VIII. INSULATION

NO. OF THUNDERSTORM DAYS/YR ________ ELEV. ABOVE SEA LEVEL *(MIN, MAX, FT)* ________

CONTAMINATION EXPECTED? ________ MAX. EST. FOOTING RESISTANCE ________ Ω SHIELD ANGLE ________ °

STRUCTURE TYPE	STRUCTURE DESIGNATION	NO. OF BELLS PIN OR POST	60 HZ DRY FLASHOVER	INSULATOR SIZE	M & E RATING OR CANTILEVER STR.	OTHER
TANGENT						
ANGLE						
STRAIN STRUCTURE						

IX. INSULATOR SWING

CRITERIA: (1)______ PSF ON BARE CONDUCTOR AT ______ °F (6 psf MIN) FOR ________ IN. CLEARANCE

(2)______ PSF HIGH WIND ON BARE CONDUCTOR AT ______ °F FOR ________ IN. CLEARANCE

ALLOWABLE ANGLE OF SWING: ANGLE IN DEGREES

STRUCTURE TYPE	NO. INSULATORS	6 PSF MIN. WIND (1)	HIGH WIND (2)	NO WIND	OTHER

X. ENVIRONMENTAL AND METEORLOGICAL DATA

TEMPERATURE: MIN ______ °F MAX ______ °F

AVERAGE YEARLY LOW ______ °F

EXTREME WIND VELOCITIES *(MPH)*:

10 YR ______ 50 YR ______ 100 YR ______

MAXIMUM HEIGHT OF SNOW ON THE GROUND UNDER THE CONDUCTOR *(FT)*

DESCRIBE TERRAIN AND CHARACTERISTICS OF SOIL

CORROSIVENESS OF ATMOSPHERE:

XI. STRUCTURE DATA

SPECIES WOOD: POLE: ________

ARM: ________

DESIGNATED BENDING FIBER STRESS *(PSI)*: POLE: ______ ARM: ______

SPANS *(FT)* FOR TANGENT TYPE ________	BASE POLE ____ FT ____ CL	OTHER HEIGHTS/CLASSES AND BRACING		
LEVEL GROUND SPAN				
MAX. HORIZON. SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH				
MAX. HORIZONTAL SPAN LIMITED BY COND. SEPARATION				
MAX. SPAN LIMITED BY UNDERBUILD				
MAX. SPAN LIMITED BY GALLOPING				

ENBEDMENT DEPTH :

PRESERVATIVE: *(Type & Retention)* POLE ________ ARM ________

GUYING: TYPE OF ANCHORS: ________ GUY SIZE AND R. B. S: ________

XII. LINE DESCRIPTION *(IF INFORMATION CAN BE ESTIMATED)*

TANGENTS ________ % LIGHT ANGLES ________ %

AVERAGE NUMBER OF LINE ANGLES PER MILE . . . . ________

MEDIUM ANGLES ________ % DEADEND AND HEAVY ANGLES ________ %

MAXIMUM DISTANCE BETWEEN FULL DEADENDS *(IN MILES)* . . . . . . ________

INSTRUCTIONS FOR FILLING OUT SAMPLE SUMMARY SHEET

I. GENERAL INFORMATION

BORROWER - REA borrower designation.

DATE - Date when design data was completed.

LINE IDENTIFICATION - The name of the line usually expressed in terms of the line's endpoints. If the line design is a "project design data" that is to be used for several line designs, the term "project design data" should be entered.

VOLTAGE - Nominal line-to-line voltage of both transmission and underbuild distribution circuit in kV. If there is no underbuild, fill in N.A. (not appropriate).

LENGTH - Self-explanatory.

TYPE OF TANGENT STRUCTURE - Give REA designation for tangent structure type used. For example, "TH-10". If the structure is not a standard REA structure, the word "special" should be filled in.

BASE POLE - The height and class of pole used most widely in line.

DESIGNED BY - Individual and/or firm doing the designing.

II. CONDUCTOR DATA

SIZE - For conductors, size in AWG numbers or kcmil. For steel wire, diameter in inches.

STRANDING - Number of strands. For ACSR conductor, give aluminum first, steel second. For example: 26/7.

MATERIAL - Indicate conductor or wire type. For example, ACSR, 6201; or EHS (extra high strength steel).

DIAMETER - Diameter of conductor in inches.

WEIGHT - Weight per foot of bare conductor.

RATED STRENGTH - Standard rated strength of conductor.

III. DESIGN LOADS

NESC LOADING DISTRICT - Indicate the National Electrical Safety Code loading district on which design is based. Use "H" for heavy, "M" for medium, and "L" for light loading district.

a. ICE - radial inches of ice on conductor for loading district specified.
b. WIND - wind force in pounds assumed to be blowing on ice covered conductor for loading district specified.
c. CONSTANT "K" - constant from NESC to be added to resultant of horizontal and vertical load (at standard loading district condition) for determining conductor sags and tensions.

HEAVY ICE - (no wind - in.) - Radial thickness of ice in inches on conductor of heavy icing condition for which line is designed (if any).

HIGH WIND - (no ice - psf) - The high wind value in pounds per square foot for which the line is designed.

OTHER - Other special load conditions, if any.

LOADING TABLE - Conductor or wire loads in pounds per linear foot for conditions indicated at left.

IV. SAG & TENSION DATA

SPANS - AVG., MAX., and RULING - Self-explanatory.

SOURCE OF SAG-TENSION DATA - Self-explanatory.

TENSION TABLE - Initial and final tension values in percent of rated strength at loading conditions indicated on the left should be given. In those boxes where there is a dotted line in the center, the specified tension limiting values* (in percent) should be given above the line and the actual resulting tension value (in percent) given below. For all other boxes the tension value should be the actual resulting value (in percent). The details of loading condition should be filled in on the left as follows:

a. UNLOADED (0^o, 15^o, 30^o) - Indicate appropriate temperature. Heavy loading district will be 0^oF, medium, 15^oF, and light, 30^oF.
b. NESC LOADED (0^o, 15^o, 30^o) - Specify appropriate temperature. Use same value as UNLOADED.
c. MAXIMUM ICE - Use the same maximum radial ice as indicated in the DESIGN LOAD section.
d. HIGH WIND - Use same value as in DESIGN LOAD section above.
e. UNLOADED LOW TEMPERATURE - Specify lowest temperature that can be expected to occur every winter.

SAG TABLE - Specify initial and/or final sags in feet for conditions indicated. Specify maximum conductor operation temperature (167^oF recommended minimum) in appropriate box on the left. Sags for the overhead ground wire and underbuild conductors are for a temperature of 120^oF.

*When sag and tension calculations are done, tension limits are usually specified at several conditions. However, usually only one of the conditions will control resulting in tensions at the other conditions to be lower than the limit.

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT - Specify maximum sag condition at which minimum clearances are to be maintained. Generally, it will be at the high temperature condition (167^{o}F recommended minimum) but it may be possible for the sag at NESC loading (H, M, L) to be the controlling case.

CLEARANCE TABLE - Indicate clearance which will be used for plan and profile and design. Extra boxes are for special situations.

VI. RIGHT-OF-WAY WIDTH

Indicate width value used. If more than one value is used, give largest and smallest value.

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING - Indicate if conductor galloping has ever occurred in the area and how often it can be expected.

HISTORY OF AEOLIAN VIBRATION - Indicate whether or not the line is in an area prone to aeolian vibration.

a. TYPE OF VIBRATION DAMPERS USED (if any) - Self-explanatory.
b. TYPE OF ARMOR RODS USED (if any) - Indicate whether standard armor rods, cushioned suspension units or nothing is used.

VIII. INSULATION

NUMBER OF THUNDERSTORM DAYS/YEAR - Self-explanatory.

ELEVATION ABOVE SEA LEVEL (min., max., ft.) - Give the altitude in feet above sea level of the minimum and maximum elevation points of the line.

CONTAMINATION EXPECTED? - Indicate contamination problems which may affect the performance of the insulation. The following are recommended terms: None, Light, Medium, Heavy, Sea Coast Area.

MAXIMUM ESTIMATED FOOTING RESISTANCE - The estimated maximum electrical footing resistance (in ohms) expected to be encountered along the length of the line. Where the footing resistance is high, the value to which the footing resistance will be reduced by using special measures should be indicated by putting this second value in parentheses. For example, 70(20)Ω.

SHIELD ANGLE - If the basic tangent structure being used is not a standard REA structure, its shield angle should be given.

INSULATION TABLE - For the structure type indicated the structure numerical designation, and the number of suspension bells should be given. If post insulators are used instead of suspension, the word "post" or "pin" should be put in the second column. The

60 Hz dry flashover value for the entire string of insulators (or post) should be given. The column "insulator size" should contain the diameter and length of the insulator. For suspension bells, the M&E strength should be given. For post insulator, the ultimate cantilever strength should be entered.

IX. INSULATOR SWING

CRITERIA - Self-explanatory.

INSULATOR SWING TABLE - For the primary structures used in the line and the number of insulators used, the insulator swing angles under the 6 pound minimum condition, the high wind condition and under the no wind condition should be given. Angles measured from a vertical through the point of insulator string suspension away from structure should be indicated by following them with an asterisk (*).

X. ENVIRONMENTAL & METEOROLOGICAL DATA

TEMPERATURE - The minimum, maximum, and average yearly low temperatures recorded in the area of the line should be given.

MAXIMUM HEIGHT OF SNOW ON GROUND UNDER CONDUCTOR (ft.) - Self-explanatory.

CORROSIVENESS OF ATMOSPHERE - Indicate corrosiveness of the atmosphere by severe, moderate, or light.

EXTREME WIND VELOCITIES - The annual extreme wind with mean recurrence intervals of 10, 50, and 100 years.

DESCRIBE TERRAIN & CHARACTER OF SOIL - A brief description should be given as to whether the terrain is flat, hilly, rolling piedmont, or mountainous. Indicate whether the soil firmness is good, average, or poor. Give approximate depth of ground water table. Describe corrosiveness of soil.

XI. STRUCTURE DATA

SPECIES WOOD - Self-explanatory.

DESIGNATED BENDING FIBER STRESS (psi) - Self-explanatory.

STRUCTURE TABLE - The various maximum span values should be given for the base pole and structure configuration. Values should also be given for other pole heights, classes or bracing and configurations that are expected to be commonly used.

a. LEVEL GROUND SPAN - Maximum span for height of pole, limited by clearance to ground only.
b. MAXIMUM HORIZONTAL SPAN LIMITED BY STRUCTURE STRENGTH - For single pole structures, this is the maximum span as limited

by pole strength. For H-frame structures, the effect of the bracing must be included. If vertical post insulators are used, their maximum horizontal span value should be included if it is less than that of the rest of the structure, and should be indicated as such by placing the term "ins" after the value. If underbuild is to be used on the line, its effect should be included.

c. MAXIMUM VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH - The maximum vertical span limited by either crossarm strength, crossarm brace strength, or horizontal post insulator strength. If horizontal post insulators are the limiting factor, the term "ins" should be placed after the span value. If the structure is such that the maximum horizontal span affects the maximum vertical span, the assumed maximum horizontal span should be the value shown in the "maximum horizontal span" box.

d. MAXIMUM HORIZONTAL SPAN LIMITED BY CONDUCTOR SEPARATION - Maximum span value using Equation 6-1 (6-2) in text.

e. MAXIMUM SPAN LIMITED BY UNDERBUILD - Give the maximum span limited by separation between underbuild conductors or between underbuild and transmission conductors, whichever is more limited.

f. MAXIMUM SPAN LIMITED BY GALLOPING - Give the maximum span that can be allowed before galloping ellipses touch.

EMBEDMENT DEPTH - Indicate the pole embedment depth used. If the standard values are used, indicate "standard"; if the other values are used, indicate by how much they differ from the standard value. For example, std + 2'.

PRESERVATIVE - Type and retention level of preservative.

GUYING - Indicate whether log, screw or other anchors are used and the predominant anchor capacity. For example, Log, 8,000/16,000 lbs. The diameter, type and rated breaking strength (rbs) of the guy strand should be given.

XII. LINE DESCRIPTION

For the respective structure types, indicate the percentage of the total number of structures used. Calculate the average number of line angles per mile and give the maximum distance in miles between full deadends*.

*Note: "Full" deadends refer to strain type structures that are designed to remain standing if all conductors and overhead ground wires are cut on either side of the structure.

NOTES

TRANSMISSION LINE DESIGN DATA SUMMARY

SAMPLE

I. GENERAL INFORMATION

BORROWER: XYZ Cooperative	DATE: 6/8/92
LINE IDENTIFICATION: Springfield - Center City	

VOLTAGE		LENGTH (Miles)	
TRANSMISSION 115 kV	UNDERBUILD NA kV	TRANSMISSION 29.7 Mi	UNDERBUILD NA Mi
TYPE OF TANGENT STRUCTURE	TH1-AAX	BASE POLE 70 Ht	3 Cl

DESIGNED BY: GH&B Consultants

II. CONDUCTOR DATA

	TRANSMISSION	OHGW	UNDERBUILD	COMMON NEUTRAL
SIZE (kcmil or IN.)	477	3/8		
STRANDING	26/7	7		
MATERIAL	ACSR	HSS		
DIAMETER (IN.)	.858	.360		
WEIGHT (LB/FT.)	.6570	.2730		
RATED STRENGTH (LBS)	19,500	10,800		

III. DESIGN LOADS

		TRANSMISSION (LBS/FT)	OHGW (LBS/FT)	UNDERBUILD (LBS/FT)	COMM. NEUTRAL (LBS/FT)
NESC: H LDG. DISTRICT					
a. ICE: ½ IN	Vertical	1.5014	.8077		
b. WIND ON ICED CONDUCTOR 4 PSF	Transverse	.6193	.4533		
c. CONSTANT K: .30	Resultant + K	1.9241	1.2262	NONE	
HEAVY ICE (NO WIND) 1 IN	Vertical	2.967	1.9642		
HIGH WIND (NO ICE) 16 PSF	Transverse	1.1440	.4800		
OTHER					

IV. SAG & TENSION DATA

SPANS AVERAGE (EST.) 763 FT. MAXIMUM (EST.) 1000 FT. RULING (EST.) 800 FT.

SOURCE OF SAG–TENSION DATA:		TRANSMISSION		OHGW		UNDERBUILD		COMMON NEUTRAL	
TENSIONS (% RATED STRENGTH)		Initial	Final	Initial	Final	Initial	Final	Initial	Final
NESC:									
a. UNLOADED (0° 15° 30°)		20	18	25	25				
	0 °F	20	17.7	25	20				
b. LOADED (0° 15° 30°)		40		50					
	0 °F	38.2		45.2					
MAXIMUM ICE 1"	32°F	61.3		53.6					
HIGH WIND (NO ICE)	30 °F	36.3		19					
UNLOADED LOW TEMPERATURE	-30 °F	22.4		26.1					
SAGS (FT)									
NESC DISTRICT LOADED	0 °F		15.3		10.0				
UNLOADED HIGH TEMP. (120° FOR OHGW & U.B.)	167 °F		21.51		13.1				
MAXIMUM ICE	32°F		23.4		16.6				
LOADED ½" ICE, NO WIND	32°F		15.4		10.1				

V. CLEARANCES

MINIMUM CLEARANCES TO BE MAINTAINED AT: 167°F Clearances rounded to nearest 1'

CLEARANCES IN FEET	RAILROADS	HIGHWAY	CULTIVATED FIELDS			ADD. ALLOW. FOR TEMPLATE
TRANSMISSION	31'	23'	23'			+1
UNDERBUILD						

VI. RIGHT OF WAY

WIDTH: 100 FT. (MIN.) 100 FT. (MAX.)

VII. CONDUCTOR MOTION DATA

HISTORY OF CONDUCTOR GALLOPING: Has occurred in area; can be severe.

HISTORY OF AEOLIAN VIBRATION: Little problem.

a. TYPE OF VIBRATION DAMPERS USED *(IF ANY)*: None.

b. TYPE OF ARMOR RODS USED *(IF ANY)*: Standard Armor Rods.

VIII. INSULATION

NO. OF THUNDERSTORM DAYS/YR 50 ELEV. ABOVE SEA LEVEL *(MIN, MAX, FT)* 2000;3200

CONTAMINATION EXPECTED? no MAX. EST. FOOTING RESISTANCE 20 Ω SHIELD ANGLE ____ °

STRUCTURE TYPE	STRUCTURE DESIGNATION	NO. OF BELLS PIN OR POST	60 HZ DRY FLASHOVER	INSULATOR SIZE	M & E RATING OR CANTILEVER STR.	OTHER
TANGENT	TH-1AAX	7	435	5-3/4"x10"	15,000 lbs	
ANGLE	TH-4A	8	485	5-3/4"x10"	25,000 lbs	
STRAIN STRUCTURE	TH-5A	9	540	5-3/4"x10"	25,000 lbs	

IX. INSULATOR SWING

CRITERIA: (1) 6 PSF ON BARE CONDUCTOR AT 0 °F (6 psf MIN) FOR 26 IN. CLEARANCE

(2) 12 PSF HIGH WIND ON BARE CONDUCTOR AT 30 °F FOR 10 IN. CLEARANCE

ALLOWABLE ANGLE OF SWING:

		ANGLE IN DEGREES			
STRUCTURE TYPE	NO. INSULATORS	6 PSF MIN. WIND (1)	HIGH WIND (2)	NO WIND	OTHER
TH-1AAX	7	55.5	78.1	22.1	
TH-4A	8	27.4*	8.1*	51.2*	

X ENVIRONMENTAL AND METEORLOGICAL DATA

TEMPERATURE: MIN -30 °F MAX 121 °F

AVERAGE YEARLY LOW -5 °F

EXTREME WIND VELOCITIES *(MPH)*:

10 YR 68 50 YR 79 100 YR 83

MAXIMUM HEIGHT OF SNOW ON THE GROUND UNDER THE CONDUCTOR *(FT)* 1.5

CORROSIVENESS OF ATMOSPHERE: light

DESCRIBE TERRAIN AND CHARACTERISTICS OF SOIL

Rolling hills and cultivated land. Soil is a sand-gravel mixture.

XI. STRUCTURE DATA

SPECIES WOOD: POLE: D. fir

ARM: D. fir

DESIGNATED BENDING FIBER STRESS *(PSI)*: POLE: 8000 ARM: 7400

SPANS *(FT)* FOR TANGENT TYPE TH-1	BASE POLE 70 FT 3 CL	OTHER HEIGHTS/CLASSES AND BRACING		
		70/3Xbrace	75/2Xbrace	
LEVEL GROUND SPAN	763	763	810	
MAX. HORIZON. SPAN LIMITED BY STRUCTURE STRENGTH	510	753	884	
MAX. VERTICAL SPAN LIMITED BY STRUCTURE STRENGTH	1720	1720	1720	
MAX. HORIZONTAL SPAN LIMITED BY COND. SEPARATION	1013	1013	1013	
MAX. SPAN LIMITED BY UNDERBUILD	NA			
MAX. SPAN LIMITED BY GALLOPING	625	625	625	

EMBEDMENT DEPTH: Standard

PRESERVATIVE: *(Type & Retention)* POLE Penta (Heavy) ARM Penta (Heavy)

GUYING: TYPE OF ANCHORS: Log 8000 GUY SIZE AND R. B. S: 3/8 HSS 10,800

XII. LINE DESCRIPTION *(IF INFORMATION CAN BE ESTIMATED)*

TANGENTS 86 % LIGHT ANGLES 8 %

MEDIUM ANGLES 1 % DEADEND AND HEAVY ANGLES 4 %

AVERAGE NUMBER OF LINE ANGLES PER MILE .... .63

MAXIMUM DISTANCE BETWEEN FULL DEADENDS *(IN MILES)* 10

SUGGESTED OUTLINE FOR DESIGN DATA SUMMARY BOOK

Given below is a suggested outline for a Design Data Summary Book. The outline is primarily intended for lines of 230 kV and below that follow REA design standards. Generally, a well prepared design data book should include all the material indicated below. However, some judgment should be used in submitting more or less information as deemed appropriate.

The starred (*) items indicate that a sample calculation and a table or results should be provided. If computer programs are utilized for calculations, the formulae and procedures used in the program should be included.

I. Transmission Line Design Data Summary

II. General Information

   A. Line identification, description and role in system

   B. Description of terrain and weather

   C. Design Criteria and Applicable Codes and Standards

   D. Selection of Conductor and OHGW

      1. Selection of Conductor and OHGW type

      2. Selection of Conductor and OHGW size-
         Economic Conductor Analysis

   E. Determination of Maximum Conductor Temperature (this section is only needed if a temperature other than 75°C (167°F) is selected).

   F. Selection of Structure Type and average height

      1. Economic evaluation of alternate structures

      2. Selection of optimum structure height

   G. Construction Cost Estimate

III. Supporting Calculations to Part I

   A. Conductor sag and tension tables (Computer Printout)

   B. OHGW sag and tension values (Computer Printout)

   C. Vertical and Horizontal Clearances and ROW Width

   D. Insulation Considerations

E. Level Ground Span*

F. Maximum span limited by conductor separation

  1. Horizontal Separation*

  2. Vertical and Diagonal Separation*

G. Maximum span limited by Underbuild (if applicable)

H. Galloping Analysis

I. Unguyed Structure Strength Calculations

  1. Maximum horizontal span limited by pole strength, 'X' bracing, pole* (including post insulators; if applicable)

  2. Maximum vertical span calculations* (including post insulators; if applicable)

  3. Hardware limitations

  4. Insulator strength requirements

J. Guyed Structure Calculations

  1. Minimum spacing of anchors*

  2. Guys and Anchor Calculations and Application Charts*

  3. Maximum Axial Loads for guyed poles*

  4. Arrangement of Guys and Anchors and Application Guides*

K. Sample insulator swing calculations and application charts for all structures*

L. Diagrams for all non-standard structures or assemblies anticipated for use on the line

M. Sag-Clearance Template (printed on transparent material)

APPENDIX B

CONDUCTOR TABLES

CONDUCTOR MECHANICAL LOADING TABLES

The tables that follow give horizontal, vertical, and resultant vector loads on conductors and overhead ground wires under standard NESC loading district conditions, high wind conditions, and heavy ice conditions. Also given are conductor strengths and conductor swing angles under an assumed six pound wind.

ACSR Conductors
NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
RAVEN	1/0	6/1	.1452	.2985	.3819	.3467	.2993	.6580	.7036	.4660	1.1439	4380	.398
QUAIL	2/0	6/1	.1831	.3353	.4320	.3998	.3157	.7094	.7719	.4823	1.2102	5310	.447
PIGEON	3/0	6/1	.2309	.3765	.4917	.4647	.3340	.7723	.8539	.5007	1.2899	6620	.502
PENGUIN	4/0	6/1	.2911	.4223	.5629	.5439	.3543	.8491	.9520	.5210	1.3853	8350	.563
WAXWING	266.8	18/1	.2894	.4568	.5907	.5565	.3697	.8681	.9789	.5363	1.4162	6880	.609
PARTRIDGE	266.8	26/7	.3673	.4815	.6556	.6446	.3807	.9486	1.0774	.5473	1.5084	11300	.642
MERLIN	336.4	18/1	.3653	.5130	.6798	.6557	.3947	.9653	1.1015	.5613	1.5363	8680	.684
LINNET	336.4	26/7	.4630	.5408	.7619	.7649	.4070	1.0664	1.2222	.5737	1.6501	14100	.721
ORIOLE	336.4	30/7	.5271	.5558	.8160	.8352	.4137	1.1320	1.2987	.5803	1.7225	17300	.741
CHICKADEE	397.5	18/1	.4316	.5573	.7548	.7403	.4143	1.0484	1.2045	.5810	1.6373	9940	.743
IBIS	397.5	26/7	.5469	.5873	.8525	.8680	.4277	1.1677	1.3446	.5943	1.7701	16300	.783
LARK	397.5	30/7	.6228	.6045	.9179	.9511	.4353	1.2460	1.4348	.6020	1.8560	20300	.806
PELICAN	477.	18/1	.5180	.6105	.8506	.8488	.4380	1.1551	1.3350	.6047	1.7656	11800	.814
FLICKER	477.	24/7	.6145	.6345	.9333	.9552	.4487	1.2554	1.4514	.6153	1.8765	17200	.846
HAWK	477.	26/7	.6570	.6435	.9696	1.0015	.4527	1.2990	1.5014	.6193	1.9241	19500	.858
HEN	477.	30/7	.7470	.6623	1.0483	1.0992	.4610	1.3920	1.6069	.6277	2.0251	23800	.883
OSPREY	556.5	18/1	.6040	.6593	.9441	.9550	.4597	1.2599	1.4614	.6263	1.8900	13700	.879
PARAKEET	556.5	24/7	.7170	.6855	1.0420	1.0789	.4713	1.3773	1.5962	.6380	2.0190	19800	.914
DOVE	556.5	26/7	.7660	.6953	1.0845	1.1319	.4757	1.4278	1.6533	.6423	2.0737	22600	.927
EAGLE	556.5	30/7	.8720	.7148	1.1775	1.2460	.4843	1.5368	1.7754	.6510	2.1910	27800	.953
KINGBIRD	636.	18/1	.6910	.7050	1.0372	1.0610	.4800	1.3645	1.5864	.6467	2.0131	15700	.940
ROOK	636.	24/7	.8190	.7328	1.1489	1.2005	.4923	1.4975	1.7374	.6590	2.1581	22000	.977
GROSBEAK	636.	26/7	.8750	.7425	1.1976	1.2605	.4967	1.5548	1.8014	.6633	2.2197	25200	.990
EGRET	636.	30/19	.9880	.7643	1.2991	1.3825	.5063	1.6723	1.9325	.6730	2.3463	31500	1.019
CUCKOO	795.	24/7	1.0240	.8190	1.3612	1.4412	.5307	1.7358	2.0139	.6973	2.4312	27900	1.092
DRAKE	795.	26/7	1.0940	.8310	1.4238	1.5162	.5360	1.8081	2.0938	.7027	2.5086	31500	1.108
MALLARD	795.	30/19	1.2350	.8550	1.5521	1.6671	.5467	1.9545	2.2547	.7133	2.6649	38400	1.140
TERN	795.	45/7	.8960	.7973	1.2493	1.3042	.5210	1.6044	1.8678	.6877	2.2904	22100	1.063
CONDOR	795.	54/7	1.0240	.8198	1.3617	1.4415	.5310	1.7362	2.0145	.6977	2.4319	28200	1.093
RAIL	954.	45/7	1.0750	.8737	1.4353	1.5149	.5550	1.8134	2.1103	.7217	2.5302	25900	1.165
CARDINAL	954.	54/7	1.2290	.8970	1.5715	1.6785	.5653	1.9712	2.2835	.7320	2.6980	33800	1.196
BUNTING	1192.5	45/7	1.3440	.9765	1.7113	1.8265	.6007	2.1227	2.4644	.7673	2.8811	32000	1.302
GRACKLE	1192.5	54/19	1.5330	1.0035	1.8822	2.0267	.6127	2.3173	2.6758	.7793	3.0870	41900	1.338
BITTERN	1272.	45/7	1.4340	1.0088	1.8033	1.9299	.6150	2.2255	2.5812	.7817	2.9969	34100	1.345
PHEASANT	1272.	54/19	1.6350	1.0365	1.9859	2.1424	.6273	2.4323	2.8052	.7940	3.2154	43600	1.382
LAPWING	1590.	45/7	1.7920	1.1265	2.1667	2.3367	.6673	2.6301	3.0368	.8340	3.4492	42200	1.502
FALCON	1590.	54/19	2.0440	1.1588	2.3996	2.6020	.6817	2.8898	3.3155	.8483	3.7223	54500	1.545
CHUKAR	1780.	84/19	2.0740	1.2015	2.4469	2.6498	.7007	2.9408	3.3810	.8673	3.7904	51000	1.602
BLUEBIRD	2156.	84/19	2.5110	1.3215	2.8875	3.1365	.7540	3.4259	3.9175	.9207	4.3242	60300	1.762

ACSR
High Wind Ldg.

ACSR Conductors
High Wind Loading

				13 LBS		16 LBS		21 LBS		26 LBS		31 LBS		6 LBS	
NAME	SIZE	STRAND	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	SWING ANGLE
RAVEN	1/0	6/1	.1452	.4312	.4550	.5307	.5502	.6965	.7115	.8623	.8745	1.0282	1.0384	.1990	53.88
QUAIL	2/0	6/1	.1831	.4843	.5177	.5960	.6235	.7823	.8034	.9605	.9857	1.1548	1.1692	.2235	50.67
PIGEON	3/0	6/1	.2309	.5438	.5908	.6693	.7080	.8785	.9083	1.0877	1.1119	1.2968	1.3172	.2510	47.39
PENGUIN	4/0	6/1	.2911	.6099	.6758	.7507	.8051	.9853	1.0274	1.2198	1.2541	1.4544	1.4833	.2815	44.04
WAXWING	266.8	18/1	.2894	.6598	.7204	.8120	.8620	1.0658	1.1043	1.3195	1.3509	1.5733	1.5996	.3045	46.46
PARTRIDGE	266.8	26/7	.3673	.6955	.7865	.8560	.9315	1.1235	1.1820	1.3910	1.4387	1.6585	1.6987	.3210	41.15
MERLIN	336.4	18/1	.3653	.7410	.8262	.9120	.9824	1.1970	1.2515	1.4820	1.5264	1.7670	1.8044	.3420	43.11
LINNET	336.4	26/7	.4630	.7811	.9080	.9613	1.0670	1.2618	1.3440	1.5622	1.6293	1.8626	1.9193	.3605	37.90
ORIOLE	336.4	30/7	.5271	.8028	.9603	.9800	1.1198	1.2968	1.3998	1.6055	1.6898	1.9143	1.9655	.3705	35.10
CHICKADEE	397.5	18/1	.4316	.8049	.9133	.9907	1.0806	1.3003	1.3700	1.6098	1.6667	1.9194	1.9673	.3715	40.72
IBIS	397.5	26/7	.5469	.8483	1.0093	1.0440	1.1786	1.3703	1.4754	1.6965	1.7825	2.0228	2.0954	.3915	35.60
LARK	397.5	30/7	.6228	.8732	1.0725	1.0747	1.2421	1.4105	1.5419	1.7463	1.8541	2.0822	2.1733	.4030	32.91
PELICAN	477.	18/1	.5180	.8818	1.0227	1.0853	1.2026	1.4245	1.5158	1.7637	1.8382	2.1028	2.1657	.4070	38.16
FLICKER	477.	24/7	.6145	.9165	1.1034	1.1280	1.2845	1.4805	1.6030	1.8330	1.9333	2.1855	2.2702	.4230	34.54
HAWK	477.	26/7	.6570	.9295	1.1383	1.1440	1.3192	1.5015	1.6389	1.8590	1.9717	2.2165	2.3118	.4290	33.14
HEN	477.	30/7	.7470	.9566	1.2137	1.1773	1.3943	1.5453	1.7163	1.9132	2.0538	2.2811	2.4003	.4415	30.58
OSPREY	556.5	18/1	.6040	.9523	1.1277	1.1720	1.3185	1.5383	1.6526	1.9045	1.9980	2.2708	2.3497	.4395	36.04
PARAKEET	556.5	24/7	.7170	.9902	1.2225	1.2187	1.4139	1.5995	1.7529	1.9803	2.1061	2.3612	2.4676	.4570	32.51
DOVE	556.5	26/7	.7660	1.0043	1.2630	1.2360	1.4541	1.6223	1.7940	2.0085	2.1496	2.3948	2.5143	.4635	31.18
EAGLE	556.5	30/7	.8720	1.0324	1.3514	1.2707	1.5411	1.6678	1.8820	2.0648	2.2414	2.4619	2.6118	.4765	28.65
KINGBIRD	636.	18/1	.6910	1.0183	1.2306	1.2533	1.4312	1.6450	1.7842	2.0367	2.1507	2.4283	2.5247	.4700	34.22
ROOK	636.	24/7	.8190	1.0584	1.3383	1.3027	1.5387	1.7090	1.8958	2.1168	2.2697	2.5239	2.6535	.4805	30.81
GROSBEAK	636.	26/7	.8750	1.0725	1.3842	1.3200	1.5837	1.7325	1.9409	2.1450	2.3166	2.5575	2.7030	.4950	29.50
EGRET	636.	30/19	.9880	1.1039	1.4815	1.3587	1.6799	1.7833	2.0387	2.2078	2.4188	2.6324	2.8117	.5095	27.28
CUCKOO	795.	24/7	1.0240	1.1830	1.5646	1.4560	1.7800	1.9110	2.1681	2.3660	2.5781	2.8210	3.0011	.5460	28.07
DRAKE	795.	26/7	1.0940	1.2003	1.6241	1.4773	1.8383	1.9390	2.2263	2.4007	2.6382	2.8623	3.0643	.5540	26.86
MALLARD	795.	30/19	1.2350	1.2350	1.7466	1.5200	1.9585	1.9950	2.3463	2.4700	2.7615	2.9450	3.1935	.5700	24.78
TERN	795.	45/7	.8960	1.1516	1.4591	1.4173	1.6768	1.8603	2.0648	2.3032	2.4713	2.7461	2.8886	.5315	30.68
CONDOR	795.	54/7	1.0240	1.1841	1.5654	1.4573	1.7811	1.9128	2.1696	2.3682	2.5801	2.8236	3.0035	.5465	28.09
RAIL	954.	45/7	1.0750	1.2621	1.6579	1.5533	1.8890	2.0388	2.3048	2.5242	2.7435	3.0096	3.1958	.5825	28.45
CARDINAL	954.	54/7	1.2290	1.2957	1.7858	1.5947	2.0133	2.0930	2.4272	2.5913	2.8680	3.0897	3.3251	.5980	25.95
BUNTING	1192.5	45/7	1.3440	1.4105	1.9483	1.7360	2.1955	2.2785	2.6454	2.8210	3.1248	3.3635	3.6221	.6510	25.84
GRACKLE	1192.5	54/19	1.5330	1.4495	2.1098	1.7840	2.3522	2.3415	2.7987	2.8990	3.2794	3.4565	3.7812	.6690	23.58
BITTERN	1272.	45/7	1.4340	1.4571	2.0444	1.7933	2.2962	2.3538	2.7562	2.9142	3.2479	3.4746	3.7589	.6725	25.13
PHEASANT	1272.	54/19	1.6350	1.4972	2.2169	1.8427	2.4635	2.4185	2.9193	2.9943	3.4116	3.5702	3.9267	.6910	22.91
LAPWING	1590.	45/7	1.7920	1.6272	2.4205	2.0027	2.6874	2.6285	3.1812	3.2543	3.7151	3.8802	4.2740	.7510	22.74
FALCON	1590.	54/19	2.0440	1.6738	2.6419	2.0600	2.9020	2.7038	3.3894	3.3475	3.9222	3.9913	4.4842	.7725	20.70
CHUKAR	1780.	84/19	2.0740	1.7355	2.7043	2.1360	2.9772	2.8035	3.4873	3.4710	4.0434	4.1385	4.6291	.8010	21.12
BLUEBIRD	2156.	84/19	2.5110	1.9088	3.1542	2.3493	3.4387	3.0835	3.9766	3.8177	4.5694	4.5518	5.1985	.8810	19.33

ACSR Conductors
Miscellaneous Loadings

NAME	SIZE	STRAND	1.0" ICE VERT. LB/FT	1.0" ICE TRANS. LB/FT	1.5" ICE VERT. LB/FT	1.5" ICE TRANS. LB/FT
RAVEN	1/0	6/1	1.8837	.1998	3.6856	.2832
QUAIL	2/0	6/1	1.9825	.2039	3.8149	.2873
PIGEON	3/0	6/1	2.0987	.2085	3.9653	.2918
PENGUIN	4/0	6/1	2.2348	.2136	4.1393	.2969
WAXWING	266.8	18/1	2.2903	.2174	4.2234	.3008
PARTRIDGE	266.8	26/7	2.4092	.2202	4.3628	.3035
MERLIN	336.4	18/1	2.4594	.2237	4.4392	.3070
LINNET	336.4	26/7	2.6031	.2268	4.6059	.3101
ORIOLE	336.4	30/7	2.6921	.2284	4.7073	.3118
CHICKADEE	397.5	18/1	2.5991	.2286	4.6155	.3119
IBIS	397.5	26/7	2.7641	.2319	4.8054	.3153
LARK	397.5	30/7	2.8686	.2338	4.9242	.3172
PELICAN	477.	18/1	2.7738	.2345	4.8343	.3178
FLICKER	477.	24/7	2.9101	.2372	4.9905	.3205
HAWK	477.	26/7	2.9675	.2382	5.0554	.3215
HEN	477.	30/7	3.0886	.2403	5.1921	.3236
OSPREY	556.5	18/1	2.9406	.2399	5.0416	.3233
PARAKEET	556.5	24/7	3.0971	.2428	5.2199	.3262
DOVE	556.5	26/7	3.1623	.2439	5.2931	.3273
EAGLE	556.5	30/7	3.3006	.2461	5.4476	.3294
KINGBIRD	636.	18/1	3.1035	.2450	5.2424	.3283
ROOK	636.	24/7	3.2775	.2481	5.4394	.3314
GROSBEAK	636.	26/7	3.3497	.2492	5.5196	.3325
EGRET	636.	30/19	3.4987	.2516	5.6867	.3349
CUCKOO	795.	24/7	3.6255	.2577	5.8589	.3410
DRAKE	795.	26/7	3.7154	.2590	5.9588	.3423
MALLARD	795.	30/19	3.8962	.2617	6.1594	.3450
TERN	795.	45/7	3.4614	.2553	5.6768	.3386
CONDOR	795.	54/7	3.6267	.2578	5.8608	.3411
RAIL	954.	45/7	3.7673	.2638	6.0461	.3471
CARDINAL	954.	54/7	3.9598	.2663	6.2579	.3497
BUNTING	1192.5	45/7	4.2066	.2752	6.5706	.3585
GRACKLE	0192.5	54/19	4.4404	.2782	6.8268	.3615
BITTERN	1272.	45/7	4.3501	.2788	6.7408	.3621
PHEASANT	1272.	54/19	4.5971	.2818	7.0108	.3652
LAPWING	1590.	45/7	4.9034	.2918	7.3917	.3752
FALCON	1590.	54/19	5.2088	.2954	7.7239	.3788
CHUKAR	1780.	84/19	5.3097	.3002	7.8602	.3835
BLUEBIRD	2156.	84/19	5.9457	.3135	8.5957	.3968

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 477 kcmil 26/7 conductor covered by 1 inch of radial ice is:

$$.2382(6) = 1.4292 \text{ lb/ft.}$$

6201
NESC Dist. Ldgs.

6201 Aluminum Alloy Conductors
NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
AZUSA	123.3	7	.1157	.2985	.3701	.3172	.2993	.6361	.6741	.4660	1.1195	4460	.398
ANAHEIM	155.4	7	.1459	.3353	.4156	.3626	.3157	.6807	.7347	.4823	1.1789	5390	.447
AMHERST	195.7	7	.1837	.3765	.4689	.4175	.3340	.7347	.8067	.5007	1.2495	6790	.502
ALLIANCE	246.9	7	.2318	.4223	.5317	.4846	.3543	.8003	.8927	.5210	1.3337	8560	.563
BUTTE	312.8	19	.2936	.4815	.6140	.5709	.3807	.8862	1.0037	.5473	1.4432	11000	.642
CANTON	394.5	19	.3703	.5408	.7054	.6722	.4070	.9858	1.1295	.5737	1.5668	13300	.721
CAIRO	465.4	19	.4369	.5873	.7819	.7580	.4277	1.0704	1.2346	.5943	1.6702	15600	.783
DARIEN	559.5	19	.5252	.6435	.8806	.8697	.4527	1.1804	1.3696	.6193	1.8031	18800	.858
ELOIN	652.4	19	.6124	.6953	.9765	.9783	.4757	1.2878	1.4997	.6423	1.9314	21900	.927
FLINT	740.8	37	.6954	.7433	1.0543	1.0612	.4970	1.3718	1.6025	.6637	2.0345	24400	.991
GREELEY	927.2	37	.8704	.8310	1.2534	1.2926	.5360	1.5993	1.8702	.7027	2.2979	30500	1.108

6201 Aluminum Alloy Conductors
High Wind Loadings

				13 LBS		16 LBS		21 LBS		26 LBS		31 LBS		6 LBS	
NAME	SIZE	STRAND	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	TOTAL LB/FT	TRANS. LB/FT	SWING ANGLE
AZUSA	123.3	7	.1157	.4312	.4464	.5307	.5431	.6965	.7060	.8623	.8701	1.0282	1.0347	.1990	59.83
ANAHEIM	155.4	7	.1459	.4843	.5058	.5960	.6136	.7823	.7957	.9685	.9794	1.1548	1.1639	.2235	56.86
AMHERST	195.7	7	.1837	.5438	.5740	.6693	.6941	.8785	.8975	1.0877	1.1031	1.2968	1.3098	.2510	53.80
ALLIANCE	246.9	7	.2318	.6099	.6525	.7507	.7856	.9853	1.0122	1.2198	1.2417	1.4544	1.4728	.2815	50.53
BUTTE	312.8	19	.2936	.6955	.7549	.8560	.9050	1.1235	1.1612	1.3910	1.4216	1.6585	1.6843	.3210	47.55
CANTON	394.5	19	.3703	.7811	.8644	.9613	1.0302	1.2618	1.3150	1.5622	1.6055	1.8626	1.8990	.3605	44.23
CAIRO	465.4	19	.4369	.8483	.9542	1.0440	1.1317	1.3703	1.4382	1.6965	1.7519	2.0228	2.0694	.3915	41.86
DARIEN	559.5	19	.5252	.9295	1.0676	1.1440	1.2588	1.5015	1.5907	1.8590	1.9318	2.2165	2.2779	.4290	39.24
ELGIN	652.4	19	.6124	1.0043	1.1762	1.2360	1.3794	1.6223	1.7340	2.0085	2.0998	2.3948	2.4718	.4635	37.12
FLINT	740.8	37	.6754	1.0736	1.2684	1.3213	1.4839	1.7343	1.8611	2.1472	2.2509	2.5601	2.6477	.4955	36.27
GREELEY	927.2	37	.8704	1.2003	1.4827	1.4773	1.7147	1.9390	2.1254	2.4007	2.5536	2.8623	2.9917	.5540	32.48

Miscellaneous Loadings

			1.0" ICE		1.5" ICE	
NAME	SIZE	STRAND	VERT. LB/FT	TRANS. LB/FT	VERT. LB/FT	TRANS. LB/FT
AZUSA	123.3	7	1.8542	.1998	3.6561	.2832
ANAHEIM	155.4	7	1.9453	.2039	3.7777	.2873
AMHERST	195.7	7	2.0515	.2085	3.9181	.2918
ALLIANCE	246.9	7	2.1755	.2136	4.0800	.2969
BUTTE	312.8	19	2.3355	.2202	4.2891	.3035
CANTON	394.5	19	2.5104	.2268	4.5132	.3101
CAIRO	465.4	19	2.6541	.2319	4.6954	.3153
DARIEN	559.5	19	2.8357	.2382	4.9236	.3215
ELGIN	652.4	19	3.0087	.2439	5.1395	.3273
FLINT	740.8	37	3.1513	.2493	5.3219	.3326
GREELEY	927.2	37	3.4918	.2590	5.7352	.3423

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 559.5 kcmil conductor covered by 1 inch of radial ice is:

$$.2382(6) = 1.4292 \text{ lb/ft.}$$

1350 (EC)
NESC Dist. Ldgs.

1350 (EC) Conductors
NESC District Loadings

			LIGHT .00"ICE 9 LB WIND K=.05			MEDIUM .25"ICE 4 LB WIND K=.20			HEAVY .50"ICE 4 LB WIND K=.30				
NAME	SIZE	STRAND	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.
POPPY	1/0	7	.0991	.2760	.3433	.2912	.2893	.6105	.6388	.4560	1.0849	1990	.368
ASTRE	2/0	7	.1249	.3105	.3847	.3313	.3047	.6501	.6932	.4713	1.1383	2510	.414
PHLOX	3/0	7	.1575	.3480	.4320	.3795	.3213	.6972	.7569	.4880	1.2006	3040	.464
OXLIP	4/0	7	.1986	.3915	.4890	.4386	.3407	.7554	.8341	.5073	1.2762	3830	.522
VALERIAN	250.	19	.2347	.4305	.5403	.4909	.3580	.8076	.9025	.5247	1.3439	4660	.574
DAISY	266.8	7	.2505	.4395	.5559	.5104	.3620	.8257	.9257	.5287	1.3661	4830	.586
LAUREL	266.8	19	.2505	.4448	.5604	.5126	.3643	.8289	.9301	.5310	1.3710	4970	.593
TULIP	336.4	19	.3158	.4995	.6410	.6006	.3887	.9154	1.0408	.5553	1.4797	6150	.666
CANNA	397.5	19	.3731	.5430	.7088	.6759	.4080	.9895	1.1342	.5747	1.5714	7110	.724
GOLDENTUFT	450.	19	.4224	.5775	.7655	.7395	.4233	1.0521	1.2121	.5900	1.6480	7890	.770
COSMOS	477.	19	.4478	.5948	.7945	.7721	.4310	1.0042	1.2518	.5977	1.6871	8360	.793
SYRINGA	477.	37	.4478	.5963	.7957	.7727	.4317	1.0851	1.2530	.5983	1.6885	8690	.795
DAHLIA	556.5	19	.5220	.6420	.8774	.8658	.4520	1.1767	1.3651	.6187	1.7988	9750	.856
MISTLETOE	556.5	37	.5220	.6435	.8786	.8665	.4527	1.1776	1.3664	.6193	1.8002	9940	.858
ORCHID	636.	37	.5970	.6885	.9613	.9601	.4727	1.2702	1.4787	.6393	1.9110	11400	.918
ARBUTUS	795.	37	.7460	.7695	1.1217	1.1427	.5087	1.4508	1.6948	.6753	2.1244	13900	1.026
LILAC	795.	61	.7460	.7710	1.1228	1.1433	.5093	1.4516	1.6961	.6760	2.1258	14300	1.028
ANEMONE	874.5	37	.8210	.8078	1.2017	1.2335	.5257	1.5409	1.8015	.6923	2.2300	15000	1.077
CROCUS	874.5	61	.8210	.8085	1.2023	1.2339	.5260	1.5413	1.8022	.6927	2.2307	15800	1.073
MAGNOLIA	954.	37	.8960	.8430	1.2802	1.3232	.5413	1.6296	1.9058	.7080	2.3330	16400	1.124
GOLDENROD	954.	61	.8960	.8445	1.2813	1.3238	.5420	1.6304	1.9070	.7087	2.3344	16900	1.126
HAWTHORN	1192.5	61	1.1190	.9435	1.5137	1.5878	.5860	1.8925	2.2121	.7527	2.6366	21100	1.258
NARCISSUS	1272.	61	1.1940	.9750	1.5915	1.6759	.6000	1.9800	2.3132	.7667	2.7369	22000	1.300

1350 (EC) Conductors
High Wind Loadings

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	13 LBS TOTAL LB/FT	16 LBS TRANS. LB/FT	16 LBS TOTAL LB/FT	21 LBS TRANS. LB/FT	21 LBS TOTAL LB/FT	26 LBS TRANS. LB/FT	26 LBS TOTAL LB/FT	31 LBS TRANS. LB/FT	31 LBS TOTAL LB/FT	6 LBS TRANS. LB/FT	6 LBS SWING ANGLE
POPPY	1/0	7	.0991	.3987	.4108	.4907	.5006	.6440	.6516	.7973	.8035	.9507	.9558	.1840	61.69
ASTRE	2/0	7	.1249	.4485	.4656	.5520	.5660	.7245	.7352	.8970	.9057	1.0695	1.0768	.2070	58.89
PHLOX	3/0	7	.1575	.5027	.5268	.6187	.6384	.8120	.8271	1.0053	1.0176	1.1987	1.2090	.2320	55.83
OXLIP	4/0	7	.1986	.5655	.5994	.6960	.7238	.9135	.9348	1.1310	1.1483	1.3485	1.3630	.2610	52.73
VALERIAN	250.	19	.2347	.6218	.6647	.7653	.8005	1.0045	1.0316	1.2437	1.2656	1.4828	1.5013	.2870	50.72
DAISY	266.8	7	.2505	.6348	.6825	.7013	.8205	1.0255	1.0557	1.2697	1.2941	1.5138	1.5344	.2930	49.47
LAUREL	266.8	19	.2505	.6424	.6895	.7907	.8294	1.0370	1.0676	1.2848	1.3090	1.5319	1.5523	.2965	49.81
TULIP	336.4	19	.3158	.7215	.7876	.8000	.9425	1.1655	1.2075	1.4430	1.4772	1.7205	1.7492	.3330	46.52
CANNA	397.5	19	.3731	.7843	.8686	.9653	1.0349	1.2670	1.3208	1.5687	1.6124	1.8703	1.9072	.3620	44.13
GOLDENTUFT	450.	19	.4224	.8342	.9350	1.0267	1.1102	1.3475	1.4122	1.6683	1.7210	1.9892	2.0335	.3850	42.35
COSMOS	477.	19	.4478	.8591	.9688	1.0573	1.1483	1.3878	1.4582	1.7182	1.7756	2.0486	2.0970	.3965	41.52
SYRINGA	477.	37	.4478	.8613	.9707	1.0600	1.1507	1.3913	1.4615	1.7225	1.7798	2.0538	2.1020	.3975	41.59
DAHLIA	556.5	19	.5220	.9273	1.0642	1.1413	1.2550	1.4980	1.5863	1.8547	1.9267	2.2113	2.2721	.4280	39.35
MISTLETOE	556.5	37	.5220	.9295	1.0660	1.1440	1.2575	1.5015	1.5896	1.8590	1.9309	2.2165	2.2771	.4290	39.41
ORCHID	636.	37	.5970	.9945	1.1599	1.2240	1.3618	1.6065	1.7138	1.9890	2.0767	2.3715	2.4455	.4590	37.55
ARBUTUS	795.	37	.7460	1.1115	1.3386	1.3680	1.5582	1.7955	1.9443	2.2230	2.3448	2.6505	2.7535	.5130	34.52
LILAC	795.	61	.7460	1.1137	1.3404	1.3707	1.5605	1.7990	1.9475	2.2273	2.3489	2.6557	2.7585	.5140	34.57
ANEMONE	874.5	37	.8210	1.1668	1.4267	1.4360	1.6541	1.8848	2.0558	2.3335	2.4737	2.7823	2.9009	.5385	33.26
CROCUS	874.5	61	.8210	1.1678	1.4275	1.4373	1.6553	1.8865	2.0574	2.3357	2.4758	2.7848	2.9033	.5390	33.29
MAGNOLIA	954.	37	.8960	1.2177	1.5118	1.4987	1.7461	1.9670	2.1615	2.4353	2.5949	2.9037	3.0388	.5620	32.10
GOLDENROD	954.	61	.8960	1.2198	1.5135	1.5013	1.7484	1.9705	2.1646	2.4397	2.5990	2.9088	3.0437	.5630	32.14
HAWTHORN	1192.5	61	1.1190	1.3628	1.7634	1.6773	2.0163	2.2015	2.4696	2.7257	2.9464	3.2498	3.4371	.6290	29.34
NARCISSUS	1272.	61	1.1940	1.4083	1.8464	1.7333	2.1048	2.2750	2.5693	2.8167	3.0593	3.3583	3.5643	.6500	28.56

1350 (EC)
Misc. Loadings

1350 (EC) Conductors
Miscellaneous Loadings

NAME	SIZE	STRAND	1.0" ICE VERT. LB/FT	1.0" ICE TRANS. LB/FT	1.5" ICE VERT. LB/FT	1.5" ICE TRANS. LB/FT
POPPY	1/0	7	1.8003	.1973	3.5835	.2807
ASTRE	2/0	7	1.8833	.2012	3.6951	.2845
PHLOX	3/0	7	1.9781	.2053	3.8210	.2887
OXLIP	4/0	7	2.0913	.2102	3.9703	.2935
VALERIAN	250.	19	2.1920	.2145	4.1034	.2978
DAISY	266.8	7	2.2228	.2155	4.1416	.2988
LAUREL	266.8	19	2.2315	.2161	4.1546	.2994
TULIP	336.4	19	2.3875	.2222	4.3561	.3055
CANNA	397.5	19	2.5170	.2270	4.5216	.3103
GOLDENTUFT	450.	19	2.6235	.2308	4.6567	.3142
COSMOS	477.	19	2.6775	.2328	4.7250	.3161
SYRINGA	477.	37	2.6800	.2329	4.7287	.3163
DAHLIA	556.5	19	2.8300	.2380	4.9167	.3213
MISTLETOE	556.5	37	2.8325	.2382	4.9204	.3215
ORCHID	636.	37	2.9821	.2432	5.1073	.3265
ARBUTUS	795.	37	3.2654	.2522	5.4578	.3355
LILAC	795.	61	3.2679	.2523	5.4615	.3357
ANEMONE	874.5	37	3.4038	.2564	5.6279	.3398
CROCUS	874.5	61	3.4051	.2565	5.6298	.3398
MAGNOLIA	954.	37	3.5373	.2603	5.7906	.3437
GOLDENROD	954.	61	3.5398	.2605	5.7943	.3438
HAWTHORN	1192.5	61	3.9269	.2715	6.2635	.3548
NARCISSUS	1272.	61	4.0542	.2750	6.4169	.3583

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 336.4 kcmil conductor covered by 1 inch of radial ice is:

$$.2222(6) = 1.3332 \text{ lb/ft.}$$

OHGW's
NESC Dist. Ldgs.
High Wind Ldgs.
Misc. Loadings

Overhead Ground Wires

NESC District Loadings

NAME	SIZE	STRAND	LIGHT .00"ICE 9 LB WIND K=.05 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	MEDIUM .25"ICE 4 LB WIND K=.20 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	HEAVY .50"ICE 4 LB WIND K=.30 VERT. LB/FT	TRANS. LB/FT	TOTAL LB/FT	ULTIMATE STRENGTH	DIAM. IN.	X-AREA SQ.IN.
HS STL	3/8	7	.2730	.2700	.4340	.4626	.2867	.7443	.8077	.4533	1.2262	10800	.360	.0792
HS STL	7/16	7	.3990	.3263	.5654	.6120	.3117	.8868	.9804	.4783	1.3908	14500	.435	.1156
EHS STL	3/8	7	.2730	.2700	.4340	.4626	.2867	.7443	.8077	.4533	1.2262	15400	.360	.0792
EHS STL	7/16	7	.3990	.3263	.5654	.6120	.3117	.8868	.9804	.4783	1.3908	20800	.435	.1156
AL CLAD	7 NO.9		.2076	.2573	.3806	.3920	.2810	.6823	.7318	.4477	1.1578	12630	.343	.0720
AL CLAD	7 NO.8		.2618	.2888	.4398	.4592	.2950	.7458	.8121	.4617	1.2341	15930	.385	.0908
AL CLAD	7 NO.7		.3300	.3248	.5130	.5423	.3110	.8252	.9101	.4777	1.3278	19060	.433	.1145

High Wind Loadings

NAME	SIZE	STRAND	VERT. LB/FT	13 LBS TRANS. LB/FT	TOTAL LB/FT	16 LBS TRANS. LB/FT	TOTAL LB/FT	21 LBS TRANS. LB/FT	TOTAL LB/FT	26 LBS TRANS. LB/FT	TOTAL LB/FT	31 LBS TRANS. LB/FT	TOTAL LB/FT	6 LBS TRANS. LB/FT	SWING ANGLE
HS STL	3/8	7	.2730	.3900	.4761	.4800	.5522	.6300	.6866	.7800	.8264	.9300	.9692	.1800	33.40
HS STL	7/16	7	.3990	.4713	.6175	.5800	.7040	.7613	.8595	.9425	1.0235	1.1238	1.1925	.2175	28.60
EHS STL	3/8	7	.2700	.3900	.4743	.4800	.5507	.6300	.6854	.7800	.8254	.9300	.9684	.1800	33.69
EHS STL	7/16	7	.3990	.4713	.6175	.5800	.7040	.7613	.8595	.9425	1.0235	1.1238	1.1925	.2175	28.60
AL CLAD	7 NO.9		.2076	.3716	.4256	.4573	.5022	.6003	.6351	.7432	.7716	.8861	.9101	.1715	39.56
AL CLAD	7 NO.8		.2618	.4171	.4924	.5133	.5762	.6738	.7228	.8342	.8743	.9946	1.0285	.1925	36.33
AL CLAD	7 NO.7		.3300	.4691	.5735	.5773	.6650	.7578	.8265	.9382	.9945	1.1186	1.1662	.2165	33.27

Miscellaneous Loadings

ICED OVERHEAD GROUND WIRE LOADINGS WITH A 1 PSF WIND

TYPE		1.0"ICE VERT. LB/FT	TRANS. LB/FT	1.5"ICE VERT. LB/FT	TRANS. LB/FT
3/8	HS STL	1.9642	.1967	3.7425	.2800
7/16	HS STL	2.1835	.2029	4.0084	.2863
3/8	EHS STL	1.9612	.1967	3.7395	.2800
7/16	EHS STL	2.1835	.2029	4.0084	.2863
7 NO.9	AL CLAD	1.8777	.1953	3.6454	.2786
7 NO.8	AL CLAD	1.9841	.1988	3.7779	.2821
7 NO.7	AL CLAD	2.1120	.2028	3.9357	.2861

Transverse loadings other than 1 psf on the indicated ice condition can be obtained by multiplying the transverse loading value in the table by the amount of the expected wind load per square foot.

For example, the transverse load caused by a 6 psf wind on a 3/8" high strength steel OHGW covered by 1" of radial ice:

$$.1967(6) = 1.1802 \text{ lb/ft.}$$

APPENDIX C

INSULATION TABLES

STRING FLASHOVER DATA
FOR 5-3/4" X 10" STANDARD SUSPENSION
INSULATORS

Units in String	60-Hz Flashover-KV Dry	60-Hz Flashover-KV Wet	Impulse Flashover-KV 1.5 X 50 Positive	Impulse Flashover-KV 1.5 X 50 Negative
2	155	90	250	250
3	215	130	355	340
4	270	170	440	415
5	325	215	525	495
6	380	255	610	585
7	435	295	695	670
8	485	335	780	760
9	540	375	860	845
10	590	415	945	930
11	640	455	1025	1015
12	690	490	1105	1105
13	735	525	1185	1190
14	785	565	1265	1275
15	830	600	1345	1360
16	875	630	1425	1440
17	920	660	1505	1530
18	965	690	1585	1615
19	1010	720	1665	1700
20	1055	750	1745	1785
21	1095	775	1820	1865
22	1135	800	1895	1945
23	1175	825	1970	2025
24	1215	850	2045	2105
25	1255	875	2120	2185

NOTES

APPENDIX D

(For future use)

APPENDIX E

WEATHER DATA

WIND VELOCITIES AND PRESSURES*

Actual Wind Velocity in kM/hr (mph)		Kilopascals (lbs./sq. ft.) on Cylindrical Surface		Kilopascals (lbs./sq. ft.) on Flat Surface	
56.3	(35)	.149	(3.1)	.230	(4.8)
64.4	(40)	.192	(4.0)	.302	(6.3)
72.4	(45)	.249	(5.2)	.388	(8.1)
78.8	(49)	.288	(6.0)	.460	(9.6)
80.5	(50)	.307	(6.4)	.479	(10.0)
88.5	(55)	.369	(7.7)	.575	(12.0)
91.2	(56.6)	.383	(8.0)	.599	(12.5)
96.7	(60)	.431	(9.0)	.676	(14.1)
104.6	(65)	.518	(10.8)	.810	(16.9)
112.7	(70)	.599	(12.5)	.934	(19.5)
120.7	(75)	.690	(14.4)	1.078	(22.5)
128.7	(80)	.786	(16.4)	1.226	(25.6)
136.8	(85)	.886	(18.5)	1.384	(28.9)
144.8	(90)	.992	(20.7)	1.547	(32.3)
152.9	(95)	1.106	(23.1)	1.729	(36.1)
160.9	(100)	1.226	(25.6)	1.916	(40.0)
169.0	(105)	1.351	(28.2)	2.112	(44.1)
177.0	(110)	1.485	(31.0)	2.318	(48.4)
185.1	(115)	1.624	(33.9)	2.538	(53.0)
193.1	(120)	1.767	(36.9)	2.763	(57.7)

*Based on:

$$F = .0025V^2 \text{ (for cylindrical surfaces)}$$

where:

F = wind force in pounds per square foot.
V = wind velocity in miles per hour.

2 Year Mean Wind

2 Year Mean Wind

Annual Extreme Wind in mph 30 feet Above Ground
2 Year Mean Recurrence Interval

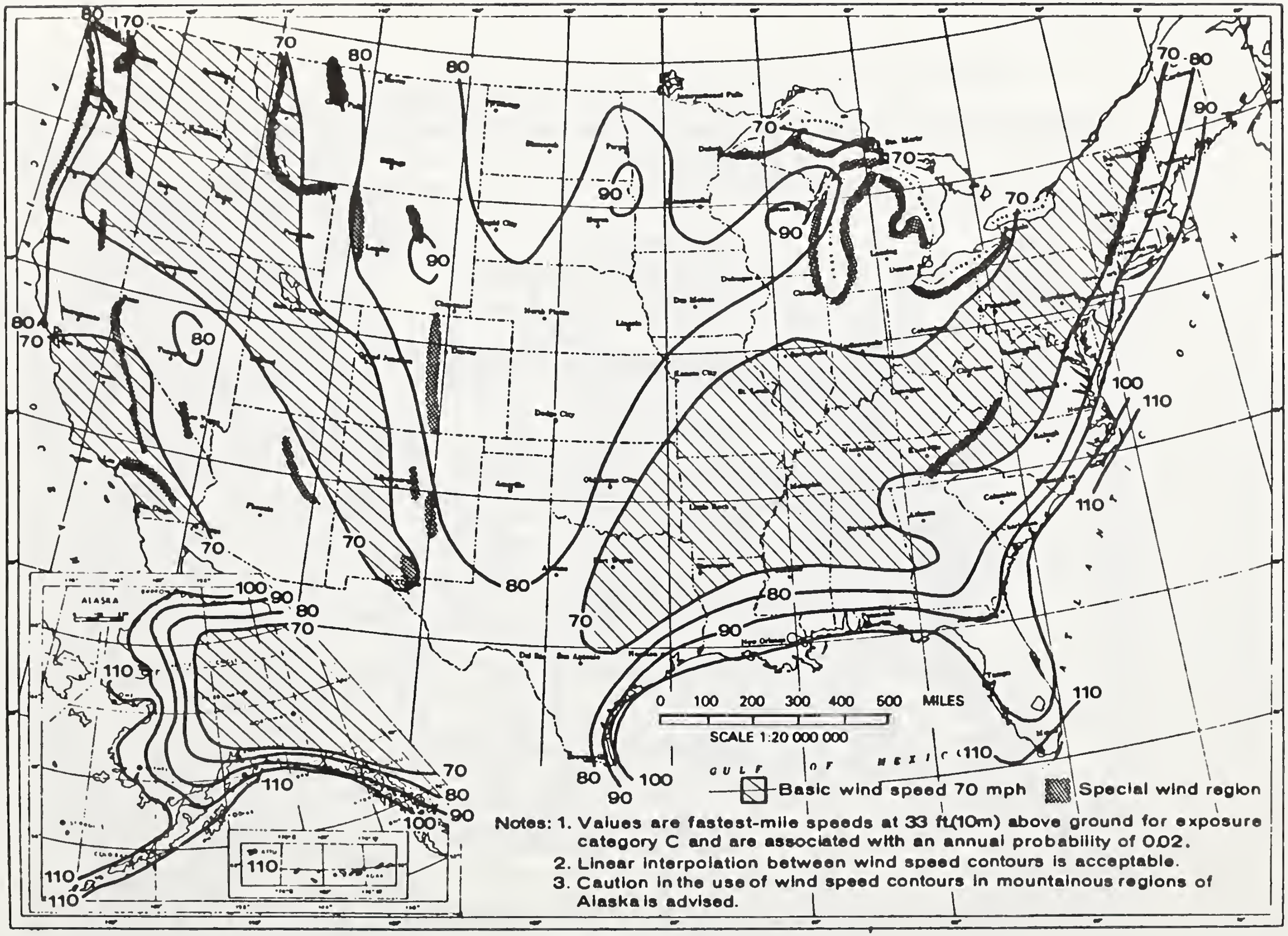
FIG. 1. - ISOTACH 0.50 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 2-YR MEAN RECURRENCE INTERVAL

Reprinted from page 5 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967

10 Year Mean Wind

Annual Extreme Wind in mph 30 feet Above Ground
10 Year Mean Recurrence Interval

FIG. 2. - ISOTACH [illegible] QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 10-YR MEAN RECURRENCE INTERVAL
Reprinted from page 6 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE
-- February 6-9, 1967



Basic Wind Speed (mph)

Reproduced from ANSI/ASCE Standard 7-88, ASCE Minimum Design Loads for Buildings and Other Structures, Copyright 1990, with permission of ASCE.

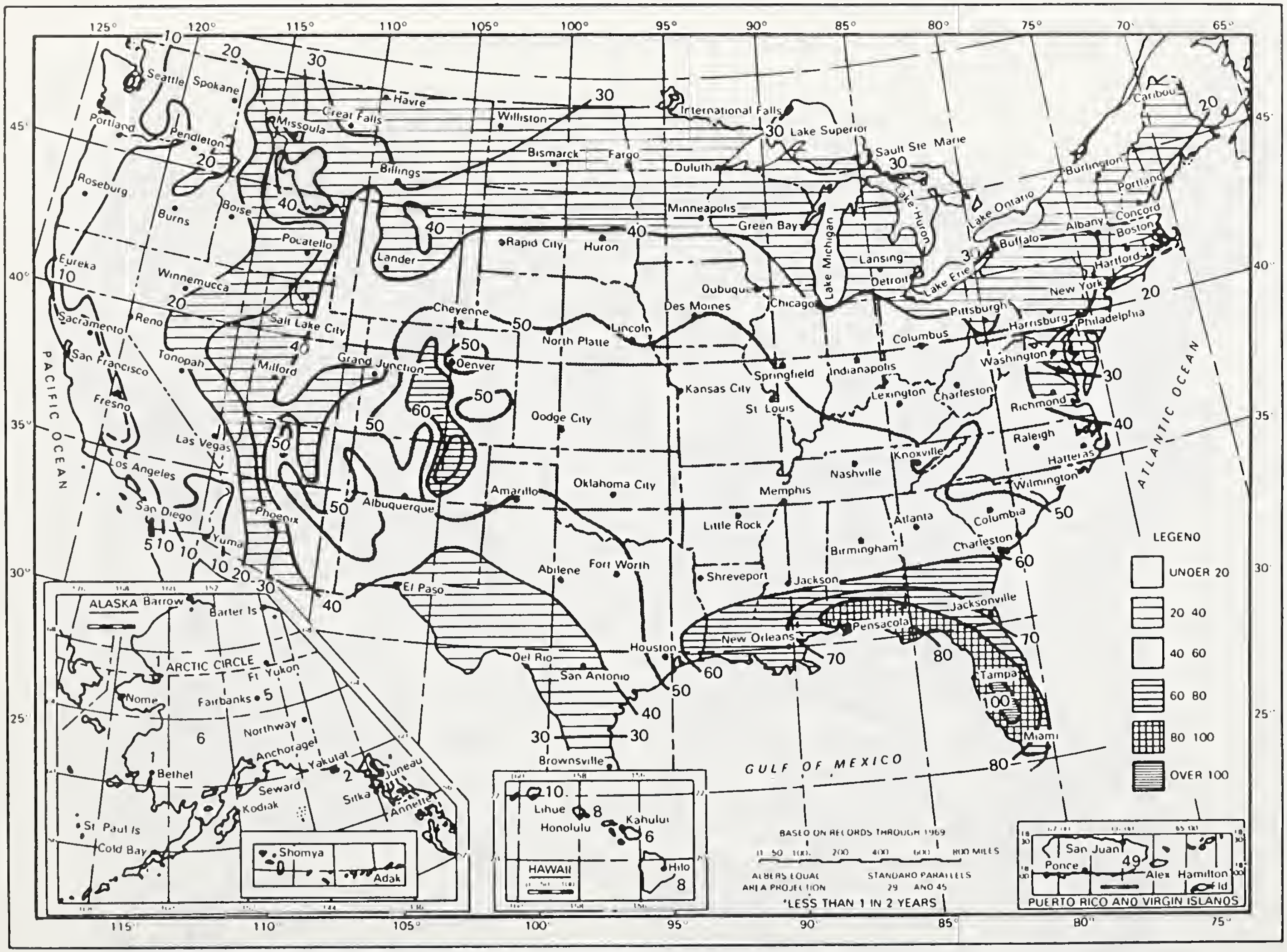
100 Year Mean Wind

Annual Extreme Wind in mph 30 feet Above Ground
100 Year Mean Recurrence Interval

FIG. 5. - ISOTACH 0.01 QUANTILES, IN MILES PER HOUR. ANNUAL EXTREME-MILE 30 FT ABOVE GROUND, 100-YR MEAN RECURRENCE INTERVAL

Reprinted from page 9 of Conference Preprint 431 - "New Distribution of Extreme Winds in the United States" by H.C.S. Thom ASCE -- February 6-9, 1967

Thunderstorm Days



Isokeraunic Levels for the United States

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APPENDIX F

POLE DATA

NOTES

Moment Capacities (ft-k) at Groundline for
Western Red Cedar (6000 psi), Lodgepole Pine (6600 psi),
Douglas Fir and Southern Yellow Pine (8000 psi),
and Western Larch (8400 psi)

		6000 PSI				6600 PSI			
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	222.2	186.1	154.2	126.2		186.9	153.9	125.1	50
55	245.4	206.9	172.7	137.9		202.5	167.8	137.2	55
60	270.4	229.3	192.7	150.4		225.5	182.5	150.2	60
65	297.1	246.7	202.4	163.7		243.4	198.2	159.0	65
70	317.7	265.1	218.6	177.9		262.4	214.8	173.4	70
75	339.4	284.4	235.7	192.9		282.4	232.4	188.8	75
80	362.2	304.8	253.8	203.1		303.4	251.0	205.1	80
85	386.1	326.2	266.0	219.6		317.5	263.6	216.1	85
90	411.1	348.6	285.6	230.7		340.4	283.8	227.5	90
95	441.6	367.3	301.9			368.0	300.5		95
100	473.4	395.5	326.6			387.8	317.7		100
105	487.2	408.0	337.8			400.9	337.7		105
110	521.2	438.1	356.0			431.5	356.3		110

		8000 PSI				8400 PSI			
HT	CL-H1	CL-1	CL-2	CL-3	CL-H1	CL-1	CL-2	CL-3	HT
50	220.3	187.2	152.1	121.7	224.2	183.9	148.7	123.0	50
55	246.4	204.2	167.1	134.7	243.6	201.1	163.8	136.4	55
60	266.8	222.3	183.0	148.7	264.3	219.4	179.9	145.4	60
65	288.4	241.5	200.0	163.5	294.4	238.9	203.5	160.4	65
70	311.2	261.9	218.1	179.4	318.0	259.5	215.3	176.4	70
75	335.3	283.4	230.3	190.2	333.8	281.3	227.7	187.3	75
80	360.6	306.2	250.2	201.5	359.6	296.1	247.8	198.7	80
85	387.2	321.5	263.7	213.3	386.7	320.0	261.5	210.6	85
90	405.2	337.5	285.5	225.5	405.0	336.2	275.8	229.9	90
95	438.0	357.3	303.2		438.3	365.6	301.5		95
100	461.5	387.3	321.5		462.1	386.7	319.9		100
105	477.7	401.9	334.6		478.7	401.7	333.4		105
110	514.2	424.1	354.1		504.0	424.1	353.1		110

Moment Capacities (ft-k) for Douglas Fir and Southern Yellow Pine Poles

The following tables give ultimate moment capacities (ft-k) of Douglas Fir and Southern Yellow Pine poles at one foot increments. The moment capacities are based on a constant 8000 psi modulus of rupture. Also included in the tables are other section properties which may be useful for design, such as diameter (inches) and area (square inches). The three columns in each table labeled 'DIST/FT' give the distance from the top of the pole in feet.

NOTES

50'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.88	53.8	8.72	59.78	43.5	1	8.08	51.29	34.5	7.44	43.44	26.9	1
2	9.50	70.86	56.1	8.85	61.58	45.4	2	8.20	52.86	36.1	7.55	44.80	28.2	2
3	9.63	72.87	58.5	8.99	63.41	47.5	3	8.33	54.45	37.8	7.67	46.18	29.5	3
4	9.77	74.91	61.0	9.12	65.26	49.6	4	8.45	56.08	39.5	7.78	47.59	30.9	4
5	9.90	76.98	63.5	9.25	67.13	51.7	5	8.57	57.72	41.2	7.90	49.02	32.3	5
6	10.03	79.07	66.1	9.38	69.04	53.9	6	8.70	59.39	43.0	8.02	50.46	33.7	6
7	10.17	81.20	68.8	9.51	70.97	56.2	7	8.82	61.08	44.9	8.13	51.93	35.2	7
8	10.30	83.35	71.6	9.64	72.93	58.6	8	8.94	62.79	46.8	8.25	53.42	36.7	8
9	10.44	85.53	74.4	9.77	74.91	61.0	9	9.06	64.53	48.7	8.36	54.93	38.3	9
10	10.57	87.74	77.3	9.90	76.92	63.4	10	9.19	66.30	50.8	8.48	56.46	39.9	10
11	10.70	89.97	80.2	10.03	78.96	66.0	11	9.31	68.08	52.8	8.59	58.01	41.5	11
12	10.84	92.24	83.3	10.16	81.03	68.6	12	9.43	69.89	54.9	8.71	59.59	43.2	12
13	10.97	94.53	86.4	10.29	83.12	71.2	13	9.56	71.73	57.1	8.83	61.18	45.0	13
14	11.10	96.85	89.6	10.42	85.23	74.0	14	9.68	73.59	59.4	8.94	62.79	46.8	14
15	11.24	99.20	92.9	10.55	87.38	76.8	15	9.80	75.47	61.6	9.06	64.43	48.6	15
16	11.37	101.58	96.3	10.68	89.55	79.7	16	9.93	77.37	64.0	9.17	66.09	50.5	16
17	11.51	103.98	99.7	10.81	91.75	82.6	17	10.05	79.30	66.4	9.29	67.77	52.5	17
18	11.64	106.41	103.2	10.94	93.97	85.7	18	10.17	81.26	68.9	9.40	69.47	54.4	18
19	11.77	108.87	106.8	11.07	96.22	88.7	19	10.29	83.23	71.4	9.52	71.19	56.5	19
20	11.91	111.36	110.5	11.20	98.50	91.9	20	10.42	85.23	74.0	9.64	72.93	58.6	20
21	12.04	113.88	114.3	11.33	100.80	95.2	21	10.54	87.26	76.6	9.75	74.69	60.7	21
22	12.18	116.44	118.1	11.46	103.13	98.5	22	10.66	89.31	79.4	9.87	76.47	62.9	22
23	12.31	119.03	122.1	11.59	105.49	101.9	23	10.79	91.38	82.1	9.98	78.28	65.1	23
24	12.44	121.60	126.1	11.72	107.87	105.3	24	10.91	93.47	85.0	10.10	80.10	67.4	24
25	12.58	124.23	130.2	11.85	110.28	108.9	25	11.03	95.59	87.9	10.21	81.95	69.8	25
26	12.71	126.89	134.4	11.98	112.72	112.5	26	11.16	97.74	90.9	10.33	83.82	72.2	26
27	12.84	129.58	138.7	12.11	115.19	116.2	27	11.28	99.90	93.9	10.45	85.71	74.6	27
28	12.98	132.29	143.1	12.24	117.68	120.0	28	11.40	102.09	97.0	10.56	87.62	77.1	28
29	13.11	135.03	147.5	12.37	120.19	123.9	29	11.52	104.31	100.2	10.68	89.55	79.7	29
30	13.25	137.80	152.1	12.50	122.74	127.9	30	11.65	106.55	103.4	10.79	91.50	82.3	30
31	13.38	140.60	156.8	12.63	125.31	131.9	31	11.77	108.81	106.7	10.91	93.47	85.0	31
32	13.51	143.43	161.5	12.76	127.90	136.0	32	11.89	111.09	110.1	11.03	95.47	87.7	32
33	13.65	146.28	166.4	12.89	130.53	140.2	33	12.02	113.40	113.6	11.14	97.48	90.5	33
34	13.78	149.17	171.3	13.02	133.18	144.5	34	12.14	115.74	117.1	11.26	99.52	93.3	34
35	13.92	152.08	176.3	13.15	135.85	148.9	35	12.26	118.09	120.7	11.37	101.58	96.3	35
36	14.05	155.02	181.5	13.28	138.56	153.4	36	12.39	120.47	124.3	11.49	103.65	99.2	36
37	14.18	157.99	186.7	13.41	141.29	157.9	37	12.51	122.88	128.1	11.60	105.75	102.3	37
38	14.32	160.98	192.1	13.54	144.04	162.6	38	12.63	125.31	131.9	11.72	107.87	105.3	38
39	14.45	164.01	197.5	13.67	146.83	167.3	39	12.75	127.76	135.8	11.84	110.01	108.5	39
40	14.58	167.06	203.0	13.80	149.64	172.1	40	12.88	130.23	139.7	11.95	112.18	111.7	40
41	14.72	170.14	208.7	13.93	152.47	177.0	41	13.00	132.73	143.8	12.07	114.36	115.0	41
42	14.85	173.25	214.4	14.06	155.34	182.0	42	13.12	135.26	147.9	12.18	116.57	118.3	42
43	14.99	176.38	220.3	14.19	158.23	187.1	43	13.25	137.80	152.1	12.30	118.79	121.7	43
44	15.12	179.55	226.2	14.32	161.14	192.3	44	13.37	140.37	156.4	12.41	121.04	125.2	44
45	15.25	182.74	232.3	14.45	164.09	197.6	45	13.49	142.97	160.7	12.53	123.31	128.7	45
46	15.39	185.96	238.4	14.58	167.06	203.0	46	13.61	145.59	165.2	12.65	125.59	132.3	46
47	15.52	189.21	244.7	14.71	170.05	208.5	47	13.74	148.23	169.7	12.76	127.90	136.0	47
48	15.66	192.49	251.1	14.84	173.08	214.1	48	13.86	150.90	174.3	12.88	130.23	139.7	48
49	15.79	195.79	257.6	14.98	176.13	219.8	49	13.98	153.59	179.0	12.99	132.59	143.5	49
50	15.92	199.12	264.2	15.11	179.20	225.6	50	14.11	156.30	183.7	13.11	134.96	147.4	50

55'
8000 psi

55'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.87	53.7	8.72	59.73	43.4	1	8.08	51.25	34.5	7.43	43.41	26.9	1
2	9.50	70.84	56.1	8.85	61.48	45.3	2	8.20	52.79	36.1	7.55	44.75	28.1	2
3	9.63	72.84	58.5	8.97	63.26	47.3	3	8.32	54.34	37.7	7.66	46.11	29.4	3
4	9.76	74.87	60.9	9.10	65.05	49.3	4	8.44	55.93	39.3	7.78	47.49	30.8	4
5	9.90	76.93	63.4	9.23	66.88	51.4	5	8.56	57.53	41.0	7.89	48.89	32.1	5
6	10.03	79.01	66.0	9.35	68.73	53.6	6	8.68	59.16	42.8	8.00	50.31	33.5	6
7	10.16	81.12	68.7	9.48	70.60	55.8	7	8.80	60.81	44.6	8.12	51.75	35.0	7
8	10.30	83.26	71.4	9.61	72.50	58.0	8	8.92	62.48	46.4	8.23	53.20	36.5	8
9	10.43	85.43	74.2	9.73	74.42	60.4	9	9.04	64.17	48.3	8.34	54.68	38.0	9
10	10.56	87.63	77.1	9.86	76.37	62.8	10	9.16	65.89	50.3	8.46	56.18	39.6	10
11	10.70	89.85	80.1	9.99	78.35	65.2	11	9.28	67.63	52.3	8.57	57.71	41.2	11
12	10.83	92.10	83.1	10.11	80.35	67.7	12	9.40	69.40	54.4	8.69	59.25	42.9	12
13	10.96	94.39	86.2	10.24	82.37	70.3	13	9.52	71.18	56.5	8.80	60.81	44.6	13
14	11.10	96.67	89.4	10.37	84.42	72.9	14	9.64	72.99	58.6	8.91	62.39	46.3	14
15	11.23	99.02	92.7	10.49	86.50	75.6	15	9.76	74.82	60.9	9.03	63.99	48.1	15
16	11.36	101.39	96.0	10.62	88.60	78.4	16	9.88	76.68	63.1	9.14	65.61	50.0	16
17	11.49	103.78	99.4	10.75	90.73	81.3	17	10.00	78.55	65.5	9.25	67.25	51.9	17
18	11.63	106.20	102.9	10.87	92.88	84.2	18	10.12	80.45	67.9	9.37	68.92	53.8	18
19	11.76	108.64	106.5	11.00	95.05	87.1	19	10.24	82.37	70.3	9.48	70.60	55.8	19
20	11.89	111.12	110.1	11.13	97.26	90.2	20	10.36	84.32	72.8	9.59	72.30	57.8	20
21	12.03	113.62	113.9	11.25	99.48	93.3	21	10.48	86.29	75.4	9.71	74.03	59.9	21
22	12.16	116.15	117.7	11.38	101.73	96.5	22	10.60	88.28	78.0	9.82	75.77	62.0	22
23	12.29	118.71	121.6	11.51	104.01	99.7	23	10.72	90.29	80.7	9.94	77.53	64.2	23
24	12.43	121.29	125.6	11.63	106.31	103.1	24	10.84	92.32	83.4	10.05	79.32	66.4	24
25	12.56	123.90	129.7	11.76	108.64	106.5	25	10.96	94.38	86.2	10.16	81.12	68.7	25
26	12.69	126.55	133.9	11.89	110.99	110.0	26	11.08	96.46	89.1	10.28	82.95	71.0	26
27	12.83	129.21	138.1	12.01	113.37	113.5	27	11.20	98.57	92.0	10.39	84.79	73.4	27
28	12.96	131.91	142.5	12.14	115.78	117.1	28	11.32	100.69	95.0	10.50	86.66	75.9	28
29	13.09	134.64	146.9	12.27	118.20	120.8	29	11.44	102.84	98.1	10.62	88.55	78.3	29
30	13.23	137.39	151.4	12.39	120.66	124.6	30	11.56	105.01	101.2	10.73	90.45	80.9	30
31	13.36	140.17	156.0	12.52	123.14	128.5	31	11.68	107.21	104.4	10.85	92.38	83.5	31
32	13.49	142.98	160.8	12.65	125.64	132.4	32	11.80	109.42	107.6	10.96	94.33	86.1	32
33	13.63	145.82	165.6	12.77	128.17	136.4	33	11.92	111.66	110.9	11.07	96.29	88.8	33
34	13.76	148.68	170.5	12.90	130.72	140.5	34	12.04	113.92	114.3	11.19	98.28	91.6	34
35	13.89	151.57	175.5	13.03	133.30	144.7	35	12.16	116.21	117.8	11.30	100.29	94.4	35
36	14.03	154.49	180.6	13.15	135.91	149.0	36	12.28	118.52	121.3	11.41	102.32	97.3	36
37	14.16	157.44	185.7	13.28	138.54	153.3	37	12.40	120.85	124.9	11.53	104.36	100.2	37
38	14.29	160.41	191.0	13.41	141.19	157.8	38	12.52	123.20	128.6	11.64	106.43	103.2	38
39	14.42	163.42	196.4	13.53	143.88	162.3	39	12.64	125.58	132.3	11.75	108.52	106.3	39
40	14.56	166.45	201.9	13.66	146.58	166.9	40	12.76	127.97	136.1	11.87	110.63	109.4	40
41	14.69	169.51	207.5	13.79	149.31	171.6	41	12.89	130.40	140.0	11.98	112.76	112.6	41
42	14.82	172.60	213.2	13.91	152.07	176.3	42	13.01	132.84	144.0	12.10	114.91	115.8	42
43	14.96	175.71	219.0	14.04	154.85	181.2	43	13.13	135.31	148.0	12.21	117.08	119.1	43
44	15.09	178.85	224.9	14.17	157.66	186.1	44	13.25	137.79	152.1	12.32	119.27	122.5	44
45	15.22	182.03	230.9	14.29	160.49	191.2	45	13.37	140.31	156.3	12.44	121.48	125.9	45
46	15.36	185.22	237.0	14.42	163.34	196.3	46	13.49	142.84	160.5	12.55	123.71	129.4	46
47	15.49	188.45	243.2	14.55	166.23	201.5	47	13.61	145.40	164.9	12.66	125.96	132.9	47
48	15.62	191.70	249.6	14.67	169.13	206.8	48	13.73	147.98	169.3	12.78	128.24	136.5	48
49	15.76	194.98	256.0	14.80	172.07	212.2	49	13.85	150.58	173.7	12.89	130.53	140.2	49
50	15.89	198.29	262.6	14.93	175.02	217:7	50	13.97	153.21	178.3	13.01	132.84	144.0	50
51	16.02	201.63	269.2	15.05	178.01	223.3	51	14.09	155.85	182.9	13.12	135.17	147.8	51
52	16.16	205.00	276.0	15.18	181.02	229.0	52	14.21	158.52	187.7	13.23	137.52	151.6	52
53	16.29	208.39	282.9	15.31	184.05	234.8	53	14.33	161.22	192.5	13.35	139.90	155.6	53
54	16.42	211.81	289.9	15.43	187.11	240.7	54	14.45	163.93	197.4	13.46	142.29	159.6	54
55	16.56	215.26	297.0	15.56	190.19	246.6	55	14.57	166.67	202.3	13.57	144.70	163.7	55

60'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.82	53.7	8.72	59.70	43.4	1	8.08	51.22	34.5	7.43	43.39	26.9	1
2	9.49	70.74	55.9	8.84	61.40	45.2	2	8.19	52.73	36.0	7.55	44.71	28.1	2
3	9.62	72.68	58.3	8.97	63.13	47.2	3	8.31	54.26	37.6	7.66	46.05	29.4	3
4	9.75	74.66	60.7	9.09	64.89	49.1	4	8.43	55.81	39.2	7.77	47.41	30.7	4
5	9.88	76.66	63.1	9.21	66.67	51.2	5	8.55	57.38	40.9	7.88	48.78	32.0	5
6	10.01	78.68	65.6	9.34	68.47	53.3	6	8.67	58.97	42.6	7.99	50.18	33.4	6
7	10.14	80.73	68.2	9.46	70.30	55.4	7	8.78	60.59	44.3	8.11	51.60	34.8	7
8	10.27	82.81	70.9	9.58	72.15	57.6	8	8.90	62.22	46.2	8.22	53.03	36.3	8
9	10.40	84.92	73.6	9.71	74.03	59.9	9	9.02	63.88	48.0	8.33	54.49	37.8	9
10	10.53	87.05	76.4	9.83	75.93	62.2	10	9.14	65.56	49.9	8.44	55.96	39.4	10
11	10.66	89.21	79.2	9.96	77.85	64.6	11	9.25	67.27	51.9	8.55	57.46	41.0	11
12	10.79	91.39	82.2	10.08	79.80	67.0	12	9.37	68.99	53.9	8.67	58.97	42.6	12
13	10.92	93.60	85.1	10.20	81.77	69.5	13	9.49	70.74	55.9	8.78	60.51	44.3	13
14	11.05	95.84	88.2	10.33	83.77	72.1	14	9.61	72.51	58.1	8.89	62.06	46.0	14
15	11.18	98.10	91.4	10.45	85.79	74.7	15	9.73	74.30	60.2	9.00	63.63	47.7	15
16	11.31	100.39	94.6	10.57	87.83	77.4	16	9.84	76.11	62.4	9.11	65.23	49.5	16
17	11.44	102.71	97.9	10.70	89.90	80.1	17	9.96	77.94	64.7	9.23	66.84	51.4	17
18	11.57	105.05	101.2	10.82	91.99	83.0	18	10.08	79.80	67.0	9.34	68.47	53.3	18
19	11.67	107.42	104.7	10.95	94.11	85.8	19	10.20	81.68	69.4	9.45	70.12	55.2	19
20	11.82	109.82	108.2	11.07	96.25	88.8	20	10.32	83.58	71.8	9.56	71.80	57.2	20
21	11.95	112.24	111.8	11.19	98.41	91.8	21	10.43	85.50	74.3	9.67	73.49	59.2	21
22	12.08	114.69	115.5	11.32	100.60	94.9	22	10.55	87.44	76.9	9.79	75.20	61.3	22
23	12.21	117.16	119.2	11.44	102.81	98.0	23	10.67	89.40	79.5	9.90	76.93	63.4	23
24	12.34	119.66	123.1	11.57	105.05	101.2	24	10.79	91.39	82.2	10.01	78.68	65.6	24
25	12.47	122.19	127.0	11.69	107.31	104.5	25	10.91	93.40	84.9	10.12	80.45	67.9	25
26	12.60	124.74	131.0	11.81	109.60	107.9	26	11.02	95.43	87.7	10.23	82.24	70.1	26
27	12.73	127.32	135.1	11.94	111.91	111.3	27	11.14	97.48	90.5	10.35	84.05	72.5	27
28	12.86	129.93	139.3	12.06	114.24	114.8	28	11.26	99.56	93.4	10.46	85.88	74.8	28
29	12.99	132.56	143.5	12.18	116.60	118.4	29	11.38	101.65	96.4	10.57	87.73	77.3	29
30	13.12	135.22	147.9	12.31	118.98	122.0	30	11.49	103.77	99.4	10.68	89.60	79.8	30
31	13.25	137.91	152.3	12.43	121.38	125.7	31	11.61	105.91	102.5	10.79	91.49	82.3	31
32	13.38	140.62	156.8	12.56	123.81	129.5	32	11.73	108.07	105.6	10.91	93.40	84.9	32
33	13.51	143.36	161.4	12.68	126.27	133.4	33	11.85	110.25	108.9	11.02	95.33	87.5	33
34	13.64	146.13	166.1	12.80	128.74	137.4	34	11.97	112.46	112.1	11.13	97.28	90.2	34
35	13.77	148.92	170.9	12.93	131.24	141.4	35	12.08	114.69	115.5	11.24	99.24	93.0	35
36	13.90	151.74	175.7	13.05	133.77	145.5	36	12.20	116.93	118.9	11.35	101.23	95.8	36
37	14.03	154.58	180.7	13.17	136.32	149.7	37	12.32	119.21	122.4	11.47	103.24	98.6	37
38	14.16	157.45	185.8	13.30	138.89	153.9	38	12.44	121.50	125.9	11.58	105.27	101.6	38
39	14.29	160.35	190.9	13.42	141.49	158.3	39	12.56	123.81	129.5	11.69	107.31	104.5	39
40	14.42	163.27	196.2	13.55	144.11	162.7	40	12.67	126.15	133.2	11.80	109.38	107.6	40
41	14.55	166.22	201.5	13.67	146.76	167.2	41	12.79	128.51	137.0	11.91	111.46	110.7	41
42	14.68	169.20	206.9	13.79	149.43	171.8	42	12.91	130.89	140.8	12.03	113.57	113.8	42
43	14.81	172.20	212.5	13.92	152.12	176.4	43	13.03	133.29	144.7	12.14	115.70	117.0	43
44	14.94	175.23	218.1	14.04	154.84	181.2	44	13.15	135.71	148.7	12.25	117.84	120.3	44
45	15.07	178.29	223.8	14.16	157.58	186.0	45	13.26	138.16	152.7	12.36	120.01	123.6	45
46	15.20	181.37	229.7	14.29	160.35	190.9	46	13.38	140.62	156.8	12.47	122.19	127.0	46
47	15.33	184.48	235.6	14.41	163.14	195.9	47	13.50	143.11	161.0	12.59	124.39	130.5	47
48	15.46	187.62	241.6	14.54	165.95	201.0	48	13.62	145.62	165.2	12.70	126.62	134.0	48
49	15.59	190.78	247.8	14.66	168.79	206.2	49	13.73	148.15	169.6	12.81	128.86	137.5	49
50	15.72	193.96	254.0	14.78	171.66	211.5	50	13.85	150.71	174.0	12.92	131.12	141.2	50
51	15.84	197.18	260.3	14.91	174.54	216.8	51	13.97	153.29	178.4	13.03	133.41	144.9	51
52	15.97	200.42	266.8	15.03	177.45	222.3	52	14.09	155.88	183.0	13.15	135.71	148.7	52
53	16.10	203.69	273.3	15.16	180.39	227.8	53	14.21	158.50	187.6	13.26	138.03	152.5	53
54	16.23	206.98	280.0	15.28	183.35	233.4	54	14.32	161.14	192.3	13.37	140.37	156.4	54
55	16.36	210.30	286.8	15.40	186.33	239.2	55	14.44	163.81	197.1	13.48	142.74	160.3	55
56	16.49	213.65	293.6	15.53	189.34	245.0	56	14.56	166.49	202.0	13.59	145.12	164.4	56
57	16.62	217.02	300.6	15.65	192.37	250.9	57	14.68	169.20	206.9	13.71	147.52	168.5	57
58	16.75	220.42	307.7	15.77	195.42	256.9	58	14.80	171.93	212.0	13.82	149.94	172.6	58
59	16.88	223.85	314.9	15.90	198.50	263.0	59	14.91	174.68	217.1	13.93	152.38	176.9	59
60	17.01	227.30	322.2	16.02	201.61	269.2	60	15.03	177.45	222.3	14.04	154.84	181.2	60

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.78	53.6	8.72	59.66	43.3	1	8.07	51.20	34.4	7.43	43.38	26.9	1
2	9.48	70.65	55.8	8.84	61.34	45.2	2	8.19	52.68	35.9	7.54	44.68	28.1	2
3	9.61	72.55	58.1	8.96	63.03	47.1	3	8.31	54.18	37.5	7.65	46.00	29.3	3
4	9.74	74.48	60.4	9.08	64.75	49.0	4	8.42	55.70	39.1	7.76	47.34	30.6	4
5	9.86	76.43	62.8	9.20	66.50	51.0	5	8.54	57.25	40.7	7.87	48.70	32.0	5
6	9.99	78.41	65.3	9.32	68.26	53.0	6	8.65	58.82	42.4	7.98	50.07	33.3	6
7	10.12	80.41	67.8	9.44	70.05	55.1	7	8.77	60.40	44.1	8.10	51.47	34.7	7
8	10.25	82.44	70.4	9.57	71.86	57.3	8	8.89	62.01	45.9	8.21	52.89	36.2	8
9	10.37	84.49	73.0	9.69	73.70	59.5	9	9.00	63.64	47.7	8.32	54.32	37.6	9
10	10.50	86.57	75.7	9.81	75.56	61.8	10	9.12	65.29	49.6	8.43	55.78	39.2	10
11	10.63	88.67	78.5	9.93	77.44	64.1	11	9.23	66.96	51.5	8.54	57.25	40.7	11
12	10.75	90.80	81.4	10.05	79.34	66.5	12	9.35	68.66	53.5	8.65	58.74	42.3	12
13	10.88	92.96	84.3	10.17	81.27	68.9	13	9.47	70.37	55.5	8.76	60.25	44.0	13
14	11.01	95.14	87.3	10.29	83.22	71.4	14	9.58	72.11	57.6	8.87	61.79	45.7	14
15	11.13	97.34	90.3	10.42	85.20	73.9	15	9.70	73.86	59.7	8.98	63.34	47.4	15
16	11.26	99.57	93.4	10.54	87.19	76.6	16	9.81	75.64	61.9	9.09	64.91	49.2	16
17	11.39	101.83	96.6	10.66	89.22	79.2	17	9.93	77.44	64.1	9.20	66.50	51.0	17
18	11.51	104.11	99.9	10.78	91.26	82.0	18	10.05	79.26	66.3	9.31	68.10	52.8	18
19	11.64	106.41	103.2	10.90	93.33	84.8	19	10.16	81.10	68.7	9.42	69.73	54.8	19
20	11.77	108.74	106.6	11.02	95.42	87.6	20	10.28	82.96	71.1	9.53	71.38	56.7	20
21	11.89	111.10	110.1	11.14	97.53	90.6	21	10.39	84.84	73.5	9.64	73.04	58.7	21
22	12.02	113.48	113.7	11.26	99.67	93.6	22	10.51	86.75	76.0	9.75	74.73	60.7	22
23	12.15	115.89	117.3	11.39	101.83	96.6	23	10.63	88.67	78.5	9.86	76.43	62.8	23
24	12.27	118.32	121.0	11.51	104.01	99.7	24	10.74	90.62	81.1	9.98	78.16	65.0	24
25	12.40	120.77	124.8	11.63	106.21	102.9	25	10.86	92.59	83.8	10.09	79.90	67.2	25
26	12.53	123.26	128.7	11.75	108.44	106.2	26	10.97	94.58	86.5	10.20	81.66	69.4	26
27	12.65	125.76	132.6	11.87	110.70	109.5	27	11.09	96.59	89.3	10.31	83.44	71.7	27
28	12.78	128.30	136.6	11.99	112.97	112.9	28	11.21	98.62	92.1	10.42	85.24	74.0	28
29	12.91	130.86	140.7	12.11	115.27	116.4	29	11.32	100.67	95.0	10.53	87.06	76.4	29
30	13.03	133.44	144.9	12.24	117.59	119.9	30	11.44	102.74	97.9	10.64	88.90	78.8	30
31	13.16	136.05	149.2	12.36	119.94	123.5	31	11.55	104.84	100.9	10.75	90.76	81.3	31
32	13.29	138.68	153.6	12.48	122.30	127.2	32	11.67	106.95	104.0	10.86	92.63	83.8	32
33	13.41	141.34	158.0	12.60	124.69	130.9	33	11.79	109.09	107.1	10.97	94.53	86.4	33
34	13.54	144.02	162.5	12.72	127.11	134.7	34	11.90	111.25	110.3	11.08	96.45	89.1	34
35	13.67	146.73	167.1	12.84	129.55	138.6	35	12.02	113.43	113.6	11.19	98.38	91.8	35
36	13.80	149.47	171.8	12.96	132.01	142.6	36	12.13	115.63	116.9	11.30	100.34	94.5	36
37	13.92	152.23	176.6	13.09	134.49	146.7	37	12.25	117.85	120.3	11.41	102.31	97.3	37
38	14.05	155.01	181.5	13.21	137.00	150.8	38	12.37	120.09	123.7	11.52	104.30	100.2	38
39	14.18	157.82	186.4	13.33	139.53	155.0	39	12.48	122.36	127.3	11.63	106.31	103.1	39
40	14.30	160.66	191.5	13.45	142.08	159.2	40	12.60	124.64	130.8	11.75	108.34	106.0	40
41	14.43	163.52	196.6	13.57	144.66	163.6	41	12.71	126.95	134.5	11.86	110.39	109.1	41
42	14.56	166.41	201.8	13.69	147.25	168.0	42	12.83	129.27	138.2	11.97	112.46	112.1	42
43	14.68	169.32	207.2	13.81	149.88	172.5	43	12.95	131.62	142.0	12.08	114.55	115.3	43
44	14.81	172.25	212.6	13.94	152.52	177.1	44	13.06	133.99	145.8	12.19	116.66	118.5	44
45	14.94	175.22	218.1	14.06	155.19	181.8	45	13.18	136.38	149.8	12.30	118.79	121.7	45
46	15.06	178.20	223.7	14.18	157.88	186.5	46	13.29	138.79	153.7	12.41	120.93	125.0	46
47	15.19	181.22	229.4	14.30	160.60	191.4	47	13.41	141.23	157.8	12.52	123.10	128.4	47
48	15.32	184.25	235.2	14.42	163.34	196.3	48	13.53	143.68	161.9	12.63	125.28	131.9	48
49	15.44	187.32	241.1	14.54	166.10	201.3	49	13.64	146.15	166.1	12.74	127.49	135.3	49
50	15.57	190.41	247.0	14.66	168.88	206.4	50	13.76	148.65	170.4	12.85	129.71	138.9	50
51	15.70	193.52	253.1	14.79	171.69	211.5	51	13.87	151.17	174.8	12.96	131.95	142.5	51
52	15.82	196.66	259.3	14.91	174.52	216.8	52	13.99	153.71	179.2	13.07	134.21	146.2	52
53	15.95	199.82	265.6	15.03	177.38	222.1	53	14.11	156.27	183.7	13.18	136.49	149.9	53
54	16.08	203.01	272.0	15.15	180.25	227.5	54	14.22	158.85	188.2	13.29	138.79	153.7	54
55	16.20	206.23	278.5	15.27	183.15	233.1	55	14.34	161.45	192.9	13.40	141.11	157.6	55
56	16.33	209.46	285.0	15.39	186.08	238.7	56	14.45	164.07	197.6	13.51	143.45	161.5	56
57	16.46	212.73	291.7	15.51	189.02	244.4	57	14.57	166.72	202.4	13.63	145.81	165.5	57
58	16.58	216.02	298.5	15.63	191.99	250.1	58	14.69	169.38	207.3	13.74	148.18	169.6	58
59	16.71	219.34	305.4	15.76	194.98	256.0	59	14.80	172.07	212.2	13.85	150.58	173.7	59
60	16.84	222.68	312.4	15.88	198.00	262.0	60	14.92	174.77	217.3	13.96	153.00	177.9	60
61	16.96	226.04	319.5	16.00	201.04	268.0	61	15.03	177.50	222.4	14.07	155.43	182.2	61
62	17.09	229.43	326.8	16.12	204.10	274.2	62	15.15	180.25	227.5	14.18	157.88	186.5	62
63	17.22	232.85	334.1	16.24	207.19	280.4	63	15.27	183.02	232.8	14.29	160.36	190.9	63
64	17.35	236.29	341.5	16.36	210.30	286.7	64	15.38	185.82	238.2	14.40	162.85	195.4	64
65	17.47	239.76	349.1	16.48	213.43	293.2	65	15.50	188.63	243.6	14.51	165.36	199.9	65

70'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.36	68.74	53.6	8.71	59.63	43.3	1	8.07	51.18	34.4	7.43	43.36	26.9	1
2	9.48	70.58	55.8	8.83	61.28	45.1	2	8.19	52.64	35.9	7.54	44.65	28.1	2
3	9.60	72.44	58.0	8.95	62.95	47.0	3	8.30	54.12	37.4	7.65	45.96	29.3	3
4	9.73	74.33	60.3	9.07	64.64	48.9	4	8.42	55.62	39.0	7.76	47.28	30.6	4
5	9.85	76.24	62.6	9.19	66.35	50.8	5	8.53	57.14	40.6	7.87	48.62	31.9	5
6	9.98	78.18	65.0	9.31	68.08	52.8	6	8.64	58.69	42.3	7.98	49.98	33.2	6
7	10.10	80.14	67.5	9.43	69.84	54.9	7	8.76	60.25	44.0	8.09	51.37	34.6	7
8	10.23	82.13	70.0	9.55	71.62	57.0	8	8.87	61.83	45.7	8.20	52.76	36.0	8
9	10.35	84.13	72.6	9.67	73.42	59.2	9	8.99	63.44	47.5	8.31	54.18	37.5	9
10	10.47	86.17	75.2	9.79	75.25	61.4	10	9.10	65.06	49.3	8.42	55.62	39.0	10
11	10.60	88.23	77.9	9.91	77.09	63.6	11	9.22	66.71	51.2	8.52	57.08	40.5	11
12	10.72	90.31	80.7	10.03	78.96	66.0	12	9.33	68.37	53.2	8.63	58.55	42.1	12
13	10.85	92.41	83.5	10.15	80.85	68.4	13	9.44	70.06	55.1	8.74	60.04	43.7	13
14	10.97	94.55	86.4	10.27	82.77	70.8	14	9.56	71.77	57.2	8.85	61.56	45.4	14
15	11.10	96.70	89.4	10.38	84.70	73.3	15	9.67	73.50	59.2	8.96	63.09	47.1	15
16	11.22	98.88	92.5	10.50	86.66	75.9	16	9.79	75.25	61.4	9.07	64.64	48.9	16
17	11.34	101.08	95.6	10.62	88.64	78.5	17	9.90	77.01	63.5	9.18	66.21	50.7	17
18	11.47	103.31	98.7	10.74	90.64	81.1	18	10.02	78.80	65.8	9.29	67.79	52.5	18
19	11.59	105.56	102.0	10.86	92.67	83.9	19	10.13	80.61	68.1	9.40	69.40	54.4	19
20	11.72	107.84	105.3	10.98	94.72	86.7	20	10.25	82.45	70.4	9.51	71.02	56.3	20
21	11.84	110.14	108.7	11.10	96.79	89.5	21	10.36	84.30	72.8	9.62	72.67	58.2	21
22	11.97	112.47	112.1	11.22	98.88	92.5	22	10.47	86.17	75.2	9.73	74.33	60.3	22
23	12.09	114.82	115.7	11.34	101.00	95.4	23	10.59	88.06	77.7	9.84	76.01	62.3	23
24	12.22	117.19	119.3	11.46	103.13	98.5	24	10.70	89.97	80.2	9.95	77.71	64.4	24
25	12.34	119.59	123.0	11.58	105.29	101.6	25	10.82	91.91	82.8	10.06	79.43	66.6	25
26	12.46	122.01	126.7	11.70	107.47	104.8	26	10.93	93.86	85.5	10.17	81.17	68.8	26
27	12.59	124.46	130.5	11.82	109.68	108.0	27	11.05	95.84	88.2	10.28	82.93	71.0	27
28	12.71	126.93	134.5	11.94	111.91	111.3	28	11.16	97.83	91.0	10.38	84.70	73.3	28
29	12.84	129.42	138.4	12.06	114.16	114.7	29	11.28	99.85	93.8	10.49	86.50	75.6	29
30	12.96	131.94	142.5	12.18	116.43	118.1	30	11.39	101.88	96.7	10.60	88.31	78.0	30
31	13.09	134.48	146.6	12.29	118.72	121.6	31	11.50	103.94	99.6	10.71	90.14	80.5	31
32	13.21	137.05	150.9	12.41	121.04	125.2	32	11.62	106.02	102.6	10.82	91.99	83.0	32
33	13.33	139.64	155.2	12.53	123.38	128.9	33	11.73	108.12	105.7	10.93	93.86	85.5	33
34	13.46	142.26	159.5	12.65	125.74	132.6	34	11.85	110.23	108.8	11.04	95.75	88.1	34
35	13.58	144.90	164.0	12.77	128.12	136.4	35	11.96	112.37	112.0	11.15	97.66	90.7	35
36	13.71	147.57	168.6	12.89	130.53	140.2	36	12.08	114.53	115.3	11.26	99.58	93.4	36
37	13.83	150.26	173.2	13.01	132.96	144.1	37	12.19	116.71	118.6	11.37	101.53	96.2	37
38	13.96	152.97	177.9	13.13	135.41	148.2	38	12.30	118.91	121.9	11.48	103.49	99.0	38
39	14.08	155.71	182.7	13.25	137.88	152.2	39	12.42	121.13	125.4	11.59	105.47	101.9	39
40	14.20	158.47	187.6	13.37	140.37	156.4	40	12.53	123.38	128.9	11.70	107.47	104.8	40
41	14.33	161.26	192.5	13.49	142.89	160.6	41	12.65	125.64	132.4	11.81	109.49	107.7	41
42	14.45	164.07	197.6	13.61	145.43	164.9	42	12.76	127.92	136.0	11.92	111.53	110.8	42
43	14.58	166.90	202.7	13.73	148.00	169.3	43	12.88	130.23	139.7	12.03	113.59	113.8	43
44	14.70	169.76	208.0	13.85	150.58	173.7	44	12.99	132.55	143.5	12.14	115.67	117.0	44
45	14.83	172.65	213.3	13.97	153.19	178.3	45	13.11	134.89	147.3	12.24	117.76	120.2	45
46	14.95	175.55	218.7	14.09	155.82	182.9	46	13.22	137.26	151.2	12.35	119.88	123.4	46
47	15.07	178.49	224.2	14.20	158.47	187.6	47	13.33	139.64	155.2	12.46	122.01	126.7	47
48	15.20	181.44	229.8	14.32	161.14	192.3	48	13.45	142.05	159.2	12.57	124.16	130.1	48
49	15.32	184.42	235.5	14.44	163.84	197.2	49	13.56	144.48	163.3	12.68	126.33	133.5	49
50	15.45	187.43	241.3	14.56	166.56	202.1	50	13.68	146.93	167.5	12.79	128.52	137.0	50
51	15.57	190.46	247.1	14.68	169.30	207.1	51	13.79	149.39	171.7	12.90	130.73	140.5	51
52	15.70	193.51	253.1	14.80	172.07	212.2	52	13.91	151.88	176.0	13.01	132.96	144.1	52
53	15.82	196.59	259.2	14.92	174.85	217.4	53	14.02	154.39	180.4	13.12	135.20	147.8	53
54	15.95	199.69	265.3	15.04	177.66	222.7	54	14.13	156.92	184.8	13.23	137.47	151.5	54
55	16.07	202.82	271.6	15.16	180.49	228.0	55	14.25	159.47	189.4	13.34	139.75	155.3	55
56	16.19	205.97	277.9	15.28	183.35	233.4	56	14.36	162.04	194.0	13.45	142.05	159.2	56
57	16.32	209.14	284.1	15.40	186.22	238.7	57	14.48	164.63	198.6	13.56	144.37	163.1	57
58	16.44	212.34	290.9	15.52	189.12	244.5	58	14.59	167.24	203.4	13.67	146.71	167.1	58
59	16.57	215.57	297.6	15.64	192.04	250.2	59	14.71	169.88	208.2	13.78	149.07	171.1	59
60	16.69	218.81	304.3	15.76	194.98	256.0	60	14.82	172.53	213.1	13.89	151.45	175.2	60
61	16.82	222.09	311.2	15.88	197.95	261.9	61	14.94	175.20	218.1	14.00	153.84	179.4	61
62	16.94	225.38	318.2	16.00	200.94	267.8	62	15.05	177.90	223.1	14.11	156.26	183.7	62
63	17.06	228.70	325.2	16.11	203.95	273.9	63	15.16	180.61	228.2	14.21	158.69	188.0	63
64	17.19	232.05	332.4	16.23	206.98	280.0	64	15.28	183.35	233.4	14.32	161.14	192.3	64
65	17.31	235.42	339.6	16.35	210.04	286.2	65	15.39	186.10	238.7	14.43	163.62	196.8	65
66	17.44	238.81	347.0	16.47	213.11	292.5	66	15.51	188.88	244.1	14.54	166.11	201.3	66
67	17.56	242.23	354.5	16.59	216.21	298.9	67	15.62	191.68	249.5	14.65	168.61	205.9	67
68	17.69	245.67	362.1	16.71	219.34	305.4	68	15.74	194.49	255.0	14.76	171.14	210.5	68
69	17.81	249.14	369.8	16.83	222.40	312.0	69	15.85	197.33	260.6	14.87	173.69	215.2	69
70	17.93	252.63	377.6	16.95	225.65	318.7	70	15.97	200.12	266.3	14.98	176.25	220.0	70

75'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3		
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	35.0	7.32	42.10	25.7	0
1	9.35	68.71	53.6	8.71	59.61	43.3	1	8.07	51.13	34.4	7.43	43.33	26.8	1
2	9.48	70.52	55.7	8.83	61.23	45.1	2	8.18	52.54	35.8	7.53	44.57	28.0	2
3	9.60	72.35	57.9	8.95	62.87	46.9	3	8.29	53.97	37.3	7.64	45.84	29.2	3
4	9.72	74.20	60.1	9.06	64.54	48.8	4	8.40	55.43	38.8	7.75	47.12	30.4	4
5	9.84	76.08	62.4	9.18	66.22	50.7	5	8.51	56.90	40.4	7.85	48.42	31.7	5
6	9.96	77.98	64.8	9.30	67.93	52.6	6	8.62	58.39	41.9	7.96	49.74	33.0	6
7	10.09	79.91	67.2	9.42	69.66	54.7	7	8.73	59.90	43.6	8.06	51.07	34.3	7
8	10.21	81.86	69.6	9.54	71.41	56.7	8	8.84	61.42	45.3	8.17	52.42	35.7	8
9	10.33	83.83	72.2	9.65	73.19	58.9	9	8.95	62.97	47.0	8.28	53.79	37.1	9
10	10.45	85.82	74.8	9.77	74.98	61.0	10	9.06	64.54	48.8	8.38	55.18	38.5	10
11	10.58	87.84	77.4	9.89	76.80	63.3	11	9.18	66.12	50.6	8.49	56.59	40.0	11
12	10.70	89.89	80.1	10.01	78.63	65.6	12	9.29	67.73	52.4	8.59	58.01	41.5	12
13	10.82	91.95	82.9	10.12	80.49	67.9	13	9.40	69.35	54.3	8.70	59.45	43.1	13
14	10.94	94.04	85.8	10.24	82.38	70.3	14	9.51	71.00	56.3	8.81	60.91	44.7	14
15	11.06	96.15	88.7	10.36	84.28	72.7	15	9.62	72.66	58.2	8.91	62.39	46.3	15
16	11.19	98.29	91.6	10.48	86.20	75.3	16	9.73	74.34	60.3	9.02	63.88	48.0	16
17	11.31	100.45	94.7	10.59	88.15	77.8	17	9.84	76.05	62.4	9.12	65.40	49.7	17
18	11.43	102.63	97.8	10.71	90.12	80.4	18	9.95	77.77	64.5	9.23	66.92	51.5	18
19	11.55	104.84	100.9	10.83	92.11	83.1	19	10.06	79.51	66.7	9.34	68.47	53.3	19
20	11.68	107.07	104.2	10.95	94.12	85.9	20	10.17	81.27	68.9	9.44	70.04	55.1	20
21	11.80	109.33	107.5	11.06	96.15	88.7	21	10.28	83.04	71.2	9.55	71.62	57.0	21
22	11.92	111.60	110.9	11.18	98.21	91.5	22	10.39	84.84	73.5	9.66	73.22	58.9	22
23	12.04	113.90	114.3	11.30	100.29	94.4	23	10.50	86.66	75.9	9.76	74.84	60.9	23
24	12.16	116.23	117.8	11.42	102.39	97.4	24	10.61	88.50	78.3	9.87	76.47	62.9	24
25	12.29	118.58	121.4	11.54	104.51	100.5	25	10.73	90.35	80.8	9.97	78.13	64.9	25
26	12.41	120.95	125.1	11.65	106.65	103.6	26	10.84	92.23	83.3	10.08	79.80	67.0	26
27	12.53	123.34	128.8	11.77	108.81	106.7	27	10.95	94.12	85.9	10.19	81.49	69.2	27
28	12.65	125.76	132.6	11.89	111.00	110.0	28	11.06	96.03	88.5	10.29	83.19	71.3	28
29	12.79	128.20	136.5	12.01	113.21	113.3	29	11.17	97.97	91.2	10.40	84.92	73.6	29
30	12.90	130.67	140.4	12.12	115.44	116.6	30	11.28	99.92	93.9	10.50	86.66	75.9	30
31	13.02	133.16	144.5	12.24	117.69	120.0	31	11.39	101.89	96.7	10.61	88.42	78.2	31
32	13.14	135.67	148.6	12.36	119.96	123.5	32	11.50	103.88	99.6	10.72	90.20	80.5	32
33	13.27	138.20	152.8	12.48	122.25	127.1	33	11.61	105.89	102.5	10.82	91.99	83.0	33
34	13.39	140.76	157.0	12.59	124.57	130.7	34	11.72	107.92	105.4	10.93	93.80	85.4	34
35	13.51	143.35	161.4	12.71	126.91	134.4	35	11.83	109.97	108.4	11.03	95.63	87.9	35
36	13.63	145.95	165.8	12.83	129.27	138.2	36	11.94	112.04	111.5	11.14	97.48	90.5	36
37	13.75	148.58	170.3	12.95	131.65	142.0	37	12.05	114.12	114.6	11.25	99.35	93.1	37
38	13.88	151.23	174.9	13.06	134.05	145.9	38	12.16	116.23	117.8	11.35	101.23	95.8	38
39	14.00	153.91	179.5	13.18	136.48	149.9	39	12.28	118.35	121.1	11.46	103.13	98.5	39
40	14.12	156.61	184.3	13.30	138.93	154.0	40	12.39	120.50	124.4	11.57	105.05	101.2	40
41	14.24	159.33	189.1	13.42	141.39	158.1	41	12.50	122.66	127.7	11.67	106.99	104.1	41
42	14.37	162.08	194.0	13.54	143.88	162.3	42	12.61	124.85	131.2	11.78	108.94	106.9	42
43	14.49	164.85	199.0	13.65	146.40	166.6	43	12.72	127.05	134.6	11.88	110.91	109.8	43
44	14.61	167.64	204.1	13.77	148.93	170.9	44	12.83	129.27	138.2	11.99	112.90	112.8	44
45	14.73	170.46	209.3	13.89	151.48	175.3	45	12.94	131.51	141.8	12.10	114.91	115.8	45
46	14.85	173.30	214.5	14.01	154.06	179.8	46	13.05	133.77	145.5	12.20	116.93	118.9	46
47	14.98	176.17	217.7	14.12	156.66	184.4	47	13.16	136.05	149.2	12.31	118.98	122.0	47
48	15.10	179.05	225.3	14.24	159.28	189.0	48	13.27	138.35	153.0	12.41	121.04	125.2	48
49	15.22	181.97	230.8	14.36	161.92	193.7	49	13.38	140.67	156.9	12.52	123.12	128.4	49
50	15.34	184.90	236.4	14.48	164.59	198.5	50	13.49	143.00	160.8	12.63	125.21	131.7	50

75'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.47	187.06	242.1	14.59	167.27	203.4	51	13.60	145.36	164.0	12.73	127.32	135.1	51
52	15.59	190.84	247.9	14.71	169.98	208.4	52	13.72	147.73	168.8	12.84	129.45	138.5	52
53	15.71	193.84	253.8	14.83	172.71	213.4	53	13.83	150.13	173.0	12.94	131.60	142.0	53
54	15.83	196.87	259.7	14.95	175.46	218.5	54	13.94	152.54	177.2	13.05	133.77	145.5	54
55	15.95	199.93	265.8	15.06	178.23	223.7	55	14.05	154.98	181.4	13.16	135.95	149.1	55
56	16.08	203.00	272.0	15.18	181.03	229.0	56	14.16	157.43	185.7	13.26	138.16	152.7	56
57	16.20	206.10	278.2	15.30	183.85	234.4	57	14.27	159.90	190.1	13.37	140.37	156.4	57
58	16.32	209.22	284.6	15.42	186.68	239.8	58	14.38	162.39	194.6	13.48	142.61	160.1	58
59	16.44	212.37	291.0	15.53	189.54	245.4	59	14.49	164.90	199.1	13.58	144.87	163.9	59
60	16.57	215.54	297.5	15.65	192.42	251.0	60	14.60	167.43	203.7	13.69	147.14	167.8	60
61	16.69	218.73	304.2	15.77	195.33	256.7	61	14.71	169.98	208.4	13.79	149.43	171.8	61
62	16.81	221.95	310.9	15.89	198.25	262.5	62	14.82	172.55	213.1	13.90	151.74	175.7	62
63	16.93	225.19	317.7	16.01	201.20	268.3	63	14.93	175.14	217.9	14.01	154.06	179.8	63
64	17.05	228.45	324.7	16.12	204.17	274.3	64	15.04	177.74	222.8	14.11	156.41	183.9	64
65	17.18	231.74	331.7	16.24	207.16	280.4	65	15.15	180.37	227.8	14.22	158.77	188.1	65
66	17.30	235.05	338.8	16.36	210.17	286.5	66	15.27	183.01	232.8	14.32	161.14	192.3	66
67	17.42	238.38	346.1	16.48	213.20	292.7	67	15.38	185.68	237.9	14.43	163.54	196.6	67
68	17.54	241.74	353.4	16.59	216.26	299.0	68	15.49	188.36	243.1	14.54	165.95	201.0	68
69	17.67	245.12	360.8	16.71	219.34	305.4	69	15.60	191.07	248.3	14.64	168.39	205.5	69
70	17.79	248.52	368.4	16.83	222.43	311.9	70	15.71	193.79	253.7	14.75	170.84	210.0	70
71	17.91	251.95	376.0	16.95	225.55	318.5	71	15.82	196.53	259.1	14.85	173.30	214.5	71
72	18.03	255.40	383.8	17.06	228.70	325.2	72	15.93	199.29	264.5	14.96	175.79	219.1	72
73	18.16	258.88	391.6	17.18	231.86	332.0	73	16.04	202.07	270.1	15.07	178.29	223.8	73
74	18.28	262.37	399.6	17.30	235.05	338.8	74	16.15	204.87	275.7	15.17	180.81	228.6	74
75	18.40	265.90	407.7	17.42	238.25	345.8	75	16.26	207.69	281.4	15.28	183.35	233.4	75

80'
8000 psi

80'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.68	53.5	8.71	59.59	43.3	1	8.07	51.12	34.4	7.42	43.29	26.8	1
2	9.47	70.46	55.6	8.83	61.19	45.0	2	8.18	52.52	35.8	7.53	44.50	27.9	2
3	9.59	72.27	57.8	8.94	62.81	46.8	3	8.29	53.93	37.2	7.63	45.73	29.1	3
4	9.71	74.09	60.0	9.06	64.45	48.7	4	8.40	55.37	38.7	7.73	46.98	30.3	4
5	9.83	75.94	62.2	9.18	66.12	50.5	5	8.51	56.83	40.3	7.84	48.24	31.5	5
6	9.95	77.81	64.5	9.29	67.80	52.5	6	8.62	58.30	41.9	7.94	49.52	32.8	6
7	10.07	79.71	66.9	9.41	69.51	54.5	7	8.73	59.80	43.5	8.04	50.82	34.1	7
8	10.19	81.63	69.3	9.52	71.23	56.5	8	8.84	61.31	45.1	8.15	52.13	35.4	8
9	10.31	83.57	71.8	9.64	72.98	58.6	9	8.94	62.84	46.8	8.25	53.46	36.8	9
10	10.44	85.53	74.4	9.76	74.75	60.8	10	9.05	64.39	48.6	8.35	54.81	38.1	10
11	10.56	87.51	77.0	9.87	76.54	63.0	11	9.16	65.96	50.4	8.46	56.17	39.6	11
12	10.68	89.52	79.6	9.99	78.35	65.2	12	9.27	67.55	52.2	8.56	57.55	41.0	12
13	10.80	91.55	82.4	10.10	80.18	67.5	13	9.38	69.16	54.1	8.66	58.94	42.6	13
14	10.92	93.61	85.2	10.22	82.04	69.9	14	9.49	70.78	56.0	8.77	60.36	44.1	14
15	11.04	95.68	88.0	10.34	83.91	72.3	15	9.60	72.43	58.0	8.87	61.79	45.7	15
16	11.16	97.78	90.9	10.45	85.81	74.7	16	9.71	74.09	60.0	8.97	63.23	47.3	16
17	11.28	99.91	93.9	10.57	87.73	77.3	17	9.82	75.78	62.0	9.08	64.70	48.9	17
18	11.40	102.05	96.9	10.68	89.67	79.8	18	9.93	77.48	64.1	9.18	66.18	50.6	18
19	11.52	104.22	100.0	10.80	91.63	82.5	19	10.04	79.20	66.3	9.28	67.68	52.3	19
20	11.64	106.41	103.2	10.92	93.61	85.2	20	10.15	80.94	68.5	9.39	69.19	54.1	20
21	11.76	108.62	106.4	11.03	95.61	87.9	21	10.26	82.70	70.7	9.49	70.72	55.9	21
22	11.88	110.86	109.8	11.15	97.63	90.7	22	10.37	84.47	73.0	9.59	72.27	57.8	22
23	12.00	113.12	113.1	11.27	99.68	93.6	23	10.48	86.27	75.3	9.70	73.83	59.6	23
24	12.12	115.40	116.6	11.38	101.74	96.5	24	10.59	88.09	77.7	9.80	75.41	61.6	24
25	12.24	117.71	120.1	11.50	103.83	99.5	25	10.70	89.92	80.2	9.90	77.01	63.5	25
26	12.36	120.03	123.7	11.61	105.94	102.5	26	10.81	91.77	82.7	10.01	78.62	65.6	26
27	12.48	122.38	127.3	11.73	108.07	105.6	27	10.92	93.64	85.2	10.11	80.25	67.6	27
28	12.60	124.76	131.0	11.85	110.22	108.8	28	11.03	95.54	87.8	10.21	81.90	69.7	28
29	12.72	127.15	134.8	11.96	112.39	112.0	29	11.14	97.44	90.4	10.31	83.57	71.8	29
30	12.84	129.57	138.7	12.08	114.58	115.3	30	11.25	99.37	93.1	10.42	85.25	74.0	30
31	12.96	132.01	142.6	12.19	116.80	118.7	31	11.36	101.32	95.9	10.52	86.94	76.2	31
32	13.09	134.48	146.6	12.31	119.03	122.1	32	11.47	103.29	98.7	10.62	88.66	78.5	32
33	13.21	136.96	150.7	12.43	121.29	125.6	33	11.58	105.27	101.6	10.73	90.39	80.8	33
34	13.33	139.47	154.9	12.54	123.57	129.2	34	11.69	107.28	104.5	10.83	92.14	83.2	34
35	13.45	142.01	159.1	12.66	125.87	132.8	35	11.80	109.30	107.4	10.93	93.90	85.6	35
36	13.57	144.56	163.4	12.78	128.19	136.5	36	11.91	111.34	110.5	11.04	95.68	88.0	36
37	13.69	147.14	167.8	12.89	130.53	140.2	37	12.02	113.40	113.6	11.14	97.48	90.5	37
38	13.81	149.74	172.3	13.01	132.89	144.0	38	12.13	115.48	116.7	11.24	99.30	93.0	38
39	13.93	152.36	176.8	13.12	135.27	147.9	39	12.24	117.59	119.9	11.35	101.13	95.6	39
40	14.05	155.01	181.5	13.24	137.68	151.9	40	12.35	119.70	123.1	11.45	102.98	98.3	40
41	14.17	157.68	186.2	13.36	140.10	155.9	41	12.45	121.84	126.4	11.55	104.84	100.9	41
42	14.29	160.37	191.0	13.47	142.55	160.0	42	12.56	123.99	129.8	11.66	106.72	103.7	42
43	14.41	163.09	195.8	13.59	145.02	164.7	43	12.67	126.17	133.2	11.76	108.62	106.4	43
44	14.53	165.82	200.8	13.70	147.51	168.5	44	12.78	128.36	136.7	11.86	110.54	109.3	44
45	14.65	168.58	205.8	13.82	150.02	172.8	45	12.89	130.57	140.3	11.97	112.47	112.2	45
46	14.77	171.37	210.9	13.94	152.55	177.2	46	13.00	132.80	143.9	12.07	114.42	115.1	46
47	14.89	174.17	216.1	14.05	155.10	181.6	47	13.11	135.05	147.6	12.17	116.39	118.1	47
48	15.01	177.00	221.4	14.17	157.68	186.2	48	13.22	137.32	151.3	12.28	118.37	121.1	48
49	15.13	179.85	226.8	14.29	160.27	190.8	49	13.33	139.61	155.1	12.38	120.37	124.2	49
50	15.25	182.73	232.3	14.40	162.89	195.5	50	13.44	141.91	159.0	12.48	122.36	127.3	50

80'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.37	185.62	237.8	14.52	165.53	200.2	51	13.55	144.24	162.9	12.59	124.42	130.5	51
52	15.49	188.54	243.4	14.63	168.19	205.1	52	13.66	146.58	166.9	12.69	126.47	133.7	52
53	15.61	191.49	249.2	14.75	170.87	210.0	53	13.77	148.95	170.9	12.79	128.53	137.0	53
54	15.73	194.45	255.0	14.87	173.57	215.0	54	13.88	151.33	175.0	12.90	130.61	140.4	54
55	15.86	197.44	260.9	14.98	176.29	220.1	55	13.99	153.73	179.2	13.00	132.71	143.8	55
56	15.98	200.45	266.9	15.10	179.04	225.3	56	14.10	156.15	183.5	13.10	134.63	147.2	56
57	16.10	203.49	272.9	15.21	181.80	230.5	57	14.21	158.59	187.8	13.21	136.96	150.7	57
58	16.22	206.54	279.1	15.33	184.59	235.8	58	14.32	161.05	192.2	13.31	139.11	154.3	58
59	16.34	209.62	285.4	15.45	187.39	241.2	59	14.43	163.52	196.6	13.41	141.28	157.9	59
60	16.46	212.72	291.7	15.56	190.22	246.7	60	14.54	166.02	201.1	13.52	143.46	161.6	60
61	16.58	215.85	298.2	15.68	193.07	252.3	61	14.65	168.53	205.7	13.62	145.66	165.3	61
62	16.70	219.00	304.7	15.80	195.94	257.9	62	14.76	171.07	210.4	13.72	147.88	169.1	62
63	16.82	222.17	311.4	15.91	198.84	263.6	63	14.87	173.62	215.1	13.82	150.11	172.9	63
64	16.94	225.36	318.1	16.03	201.75	269.4	64	14.98	176.19	219.9	13.93	152.36	176.8	64
65	17.06	228.58	324.9	16.14	204.68	275.3	65	15.09	178.78	224.8	14.03	154.63	180.3	65
66	17.18	231.82	331.9	16.26	207.64	281.3	66	15.20	181.39	229.7	14.13	156.91	184.8	66
67	17.30	235.08	338.9	16.38	210.62	287.4	67	15.31	184.02	234.7	14.24	159.21	188.9	67
68	17.42	238.36	346.0	16.49	213.61	293.6	68	15.42	186.67	239.8	14.34	161.53	193.0	68
69	17.54	241.67	353.3	16.61	216.63	299.8	69	15.53	189.33	245.0	14.44	163.87	197.2	69
70	17.66	245.00	360.6	16.72	219.67	306.1	70	15.64	192.02	250.2	14.55	166.22	201.5	70
71	17.78	248.35	368.0	16.84	222.74	312.6	71	15.75	194.72	255.5	14.65	168.58	205.8	71
72	17.90	251.73	375.5	16.96	225.82	319.1	72	15.86	197.44	260.9	14.75	170.97	210.2	72
73	18.02	255.13	383.2	17.07	228.92	325.7	73	15.96	200.18	266.3	14.86	173.37	214.6	73
74	18.14	258.55	390.9	17.19	232.05	332.4	74	16.07	202.94	271.8	14.96	175.79	219.1	74
75	18.26	261.99	398.7	17.30	235.19	339.2	75	16.18	205.72	277.4	15.06	178.22	223.7	75
76	18.38	265.46	406.7	17.42	238.36	346.0	76	16.29	208.52	283.1	15.17	180.67	228.3	76
77	18.51	268.95	414.7	17.54	241.55	353.0	77	16.40	211.34	288.9	15.27	183.14	233.0	77
78	18.63	272.46	422.9	17.65	244.76	360.1	78	16.51	214.17	294.7	15.37	185.62	237.8	78
79	18.75	276.00	431.1	17.77	247.99	367.2	79	16.62	217.03	300.6	15.48	188.13	242.6	79
80	18.87	279.55	439.5	17.89	251.24	374.5	80	16.73	219.90	306.6	15.58	190.64	247.5	80

85'
8000 psi

85'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.66	53.5	8.71	59.55	43.2	1	8.06	51.08	34.3	7.42	43.26	26.8	1
2	9.47	70.42	55.6	8.82	61.10	44.9	2	8.17	52.44	35.7	7.52	44.45	27.9	2
3	9.59	72.20	57.7	8.93	62.67	46.7	3	8.28	53.82	37.1	7.62	45.64	29.0	3
4	9.71	74.00	59.9	9.05	64.26	48.4	4	8.38	55.22	38.6	7.72	46.86	30.2	4
5	9.83	75.82	62.1	9.16	65.88	50.3	5	8.49	56.63	40.1	7.82	48.09	31.4	5
6	9.94	77.67	64.4	9.27	67.51	52.2	6	8.60	58.07	41.6	7.93	49.33	32.6	6
7	10.06	79.53	66.7	9.38	69.16	54.1	7	8.71	59.52	43.2	8.03	50.60	33.8	7
8	10.18	81.42	69.1	9.50	70.84	56.1	8	8.81	60.99	44.8	8.13	51.87	35.1	8
9	10.30	83.34	71.5	9.61	72.53	58.1	9	8.92	62.47	46.4	8.23	53.17	36.5	9
10	10.42	85.27	74.0	9.72	74.24	60.1	10	9.03	63.98	48.1	8.33	54.48	37.8	10
11	10.54	87.23	76.6	9.84	75.98	62.3	11	9.13	65.50	49.8	8.43	55.80	39.2	11
12	10.66	89.20	79.2	9.95	77.73	64.4	12	9.24	67.04	51.6	8.53	57.14	40.6	12
13	10.78	91.21	81.9	10.06	79.50	66.7	13	9.35	68.60	53.4	8.63	58.50	42.1	13
14	10.90	93.23	84.6	10.17	81.29	68.9	14	9.45	70.18	55.3	8.73	59.88	43.6	14
15	11.01	95.27	87.4	10.29	83.11	71.2	15	9.56	71.77	57.2	8.83	61.27	45.1	15
16	11.13	97.34	90.3	10.40	84.94	73.6	16	9.67	73.38	59.1	8.93	62.67	46.7	16
17	11.25	99.43	93.2	10.51	86.79	76.0	17	9.77	75.01	61.1	9.03	64.09	48.2	17
18	11.37	101.54	96.2	10.63	88.67	78.5	18	9.88	76.66	63.1	9.13	65.53	49.9	18
19	11.49	103.68	99.3	10.74	90.56	81.0	19	9.99	78.33	65.2	9.24	66.98	51.5	19
20	11.61	105.83	102.4	10.85	92.47	83.6	20	10.09	80.01	67.3	9.34	68.45	53.3	20
21	11.73	108.01	105.6	10.96	94.40	86.2	21	10.20	81.71	69.5	9.44	69.94	55.0	21
22	11.85	110.21	108.8	11.08	96.36	88.9	22	10.31	83.43	71.7	9.54	71.44	56.8	22
23	11.96	112.44	112.1	11.19	98.33	91.7	23	10.41	85.17	73.9	9.64	72.96	58.6	23
24	12.08	114.68	115.5	11.30	100.32	94.5	24	10.52	86.93	76.2	9.74	74.49	60.4	24
25	12.20	116.95	118.9	11.41	102.34	97.3	25	10.63	88.70	78.5	9.84	76.04	62.3	25
26	12.32	119.24	122.4	11.53	104.37	100.3	26	10.73	90.49	80.9	9.94	77.60	64.3	26
27	12.44	121.55	126.0	11.64	106.42	103.2	27	10.84	92.30	83.4	10.04	79.18	66.3	27
28	12.56	123.88	129.6	11.75	108.49	106.3	28	10.95	94.13	85.9	10.14	80.78	68.3	28
29	12.68	126.24	133.4	11.87	110.59	109.3	29	11.05	95.97	88.4	10.24	82.39	70.3	29
30	12.80	128.62	137.2	11.98	112.70	112.5	30	11.16	97.84	91.0	10.34	84.02	72.4	30
31	12.92	131.02	141.0	12.09	114.83	115.7	31	11.27	99.72	93.6	10.44	85.67	74.6	31
32	13.03	133.44	144.9	12.20	116.99	119.0	32	11.37	101.62	96.3	10.54	87.33	76.7	32
33	13.15	135.88	148.9	12.32	119.16	122.3	33	11.48	103.53	99.1	10.65	89.00	79.0	33
34	13.27	138.35	153.0	12.43	121.35	125.7	34	11.59	105.47	101.8	10.75	90.69	81.2	34
35	13.39	140.84	157.2	12.54	123.56	129.2	35	11.69	107.42	104.7	10.85	92.40	83.5	35
36	13.51	143.35	161.4	12.66	125.80	132.7	36	11.80	109.39	107.6	10.95	94.13	85.9	36
37	13.63	145.89	165.7	12.77	128.05	136.2	37	11.91	111.38	110.5	11.05	95.87	88.3	37
38	13.75	148.44	170.1	12.88	130.32	139.9	38	12.02	113.38	113.5	11.15	97.62	90.7	38
39	13.87	151.02	174.5	12.99	132.62	143.6	39	12.12	115.41	116.6	11.25	99.40	93.2	39
40	13.99	153.62	179.0	13.11	134.93	147.4	40	12.23	117.45	119.7	11.35	101.18	95.7	40
41	14.10	156.24	183.6	13.22	137.26	151.2	41	12.34	119.51	122.8	11.45	102.99	98.3	41
42	14.22	158.89	188.3	13.33	139.61	155.1	42	12.44	121.59	126.1	11.55	104.81	100.9	42
43	14.34	161.55	193.1	13.45	141.99	159.1	43	12.55	123.68	129.3	11.65	106.64	103.6	43
44	14.46	164.24	197.9	13.56	144.38	163.1	44	12.66	125.80	132.7	11.75	108.49	106.3	44
45	14.58	166.95	202.8	13.67	146.79	167.2	45	12.76	127.93	136.1	11.85	110.36	109.0	45
46	14.70	169.69	207.8	13.78	149.23	171.4	46	12.87	130.08	139.5	11.95	112.25	111.8	46
47	14.82	172.44	212.9	13.90	151.68	175.6	47	12.98	132.25	143.0	12.06	114.15	114.7	47
48	14.94	175.22	218.1	14.01	154.15	180.0	48	13.08	134.43	146.6	12.16	116.06	117.6	48
49	15.06	178.02	223.3	14.12	156.64	184.3	49	13.19	136.63	150.2	12.26	117.99	120.5	49
50	15.17	180.84	228.7	14.24	159.16	188.8	50	13.30	138.86	153.9	12.36	119.94	123.5	50

85'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.29	183.69	234.1	14.35	161.69	193.3	51	13.40	141.09	157.6	12.46	121.90	126.6	51
52	15.41	186.55	239.6	14.46	164.24	197.9	52	13.51	143.35	161.4	12.56	123.88	129.6	52
53	15.53	189.44	245.2	14.57	166.81	202.6	53	13.62	145.63	165.2	12.66	125.88	132.8	53
54	15.65	192.35	250.8	14.69	169.41	207.3	54	13.72	147.92	169.2	12.76	127.89	136.0	54
55	15.77	195.28	256.6	14.80	172.02	212.1	55	13.83	150.23	173.1	12.86	129.92	139.2	55
56	15.89	198.24	262.4	14.91	174.65	217.0	56	13.94	152.56	177.2	12.96	131.96	142.5	56
57	16.01	201.22	268.4	15.03	177.31	222.0	57	14.04	154.91	181.3	13.06	134.02	145.9	57
58	16.13	204.22	274.4	15.14	179.98	227.0	58	14.15	157.27	185.4	13.16	136.09	149.3	58
59	16.24	207.24	280.5	15.25	182.67	232.1	59	14.26	159.65	189.7	13.26	138.18	152.7	59
60	16.36	210.28	286.7	15.36	185.38	237.3	60	14.36	162.05	194.0	13.36	140.29	156.2	60
61	16.48	213.35	293.0	15.48	188.12	242.6	61	14.47	164.47	198.3	13.47	142.41	159.8	61
62	16.60	216.44	299.4	15.59	190.87	247.9	62	14.58	166.91	202.8	13.57	144.55	163.4	62
63	16.72	219.55	305.9	15.70	193.64	253.4	63	14.68	169.36	207.2	13.67	146.71	167.1	63
64	16.84	222.68	312.4	15.81	196.43	258.9	64	14.79	171.83	211.8	13.77	148.88	170.8	64
65	16.96	225.83	319.1	15.93	199.25	264.4	65	14.90	174.32	216.4	13.87	151.06	174.6	65
66	17.08	229.01	325.9	16.04	202.08	270.1	66	15.00	176.83	221.1	13.97	153.27	178.4	66
67	17.19	232.21	332.7	16.15	204.93	275.8	67	15.11	179.36	225.9	14.07	155.48	182.3	67
68	17.31	235.43	339.7	16.27	207.80	281.7	68	15.22	181.90	230.7	14.17	157.72	186.2	68
69	17.43	238.68	346.7	16.38	210.70	287.6	69	15.33	184.46	235.6	14.27	159.97	190.2	69
70	17.55	241.74	353.9	16.49	213.61	293.6	70	15.43	187.04	240.5	14.37	162.23	194.3	70
71	17.67	245.23	361.1	16.60	216.54	299.6	71	15.54	189.64	245.5	14.47	164.52	198.4	71
72	17.79	248.54	368.4	16.72	219.49	305.8	72	15.65	192.25	250.6	14.57	166.81	202.6	72
73	17.91	251.87	375.9	16.83	222.47	312.0	73	15.75	194.89	255.8	14.67	169.13	206.8	73
74	18.03	255.23	383.4	16.94	225.46	318.3	74	15.86	197.54	261.0	14.78	171.46	211.1	74
75	18.15	258.60	391.0	17.06	228.47	324.7	75	15.97	200.20	266.4	14.88	173.80	215.4	75
76	18.26	262.00	398.8	17.17	231.50	331.2	76	16.07	202.89	271.7	14.98	176.17	219.9	76
77	18.38	265.43	406.6	17.28	234.56	337.8	77	16.18	205.60	277.2	15.08	178.54	224.3	77
78	18.50	268.87	414.5	17.39	237.63	344.4	78	16.29	208.32	282.7	15.18	180.94	228.8	78
79	18.62	272.33	422.6	17.51	240.72	351.2	79	16.39	211.06	288.3	15.28	183.35	233.4	79
80	18.74	275.82	430.7	17.62	243.83	358.0	80	16.50	213.82	294.0	15.38	185.77	238.1	80
81	18.86	279.33	439.0	17.73	246.97	364.9	81	16.61	216.59	299.7	15.48	188.21	242.8	81
82	18.98	282.86	447.3	17.85	250.12	371.9	82	16.71	219.39	305.5	15.58	190.67	247.6	82
83	19.10	286.42	455.8	17.96	253.29	379.0	83	16.82	222.20	311.4	15.68	193.14	252.4	83
84	19.22	290.00	464.3	18.07	256.48	386.2	84	16.93	225.03	317.4	15.78	195.63	257.3	84
85	19.33	293.59	473.0	18.18	259.70	393.5	85	17.03	227.88	323.5	15.88	198.14	262.2	85

90'
8000 psi

90'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.61	53.4	8.70	59.51	43.2	1	8.06	51.07	34.3	7.42	43.24	26.7	1
2	9.46	70.32	55.4	8.81	61.02	44.8	2	8.17	52.42	35.7	7.52	44.39	27.8	2
3	9.58	72.05	57.5	8.92	62.55	46.5	3	8.28	53.79	37.1	7.62	45.56	28.9	3
4	9.69	73.80	59.6	9.03	64.10	48.3	4	8.38	55.18	38.5	7.72	46.75	30.1	4
5	9.81	75.57	61.8	9.14	65.67	50.0	5	8.49	56.59	40.0	7.81	47.95	31.2	5
6	9.92	77.36	64.0	9.25	67.25	51.9	6	8.59	58.01	41.5	7.91	49.17	32.4	6
7	10.04	79.17	66.2	9.36	68.86	53.7	7	8.70	59.45	43.1	8.01	50.40	33.6	7
8	10.16	81.00	68.5	9.47	70.49	55.6	8	8.81	60.91	44.7	8.11	51.65	34.9	8
9	10.27	82.86	70.9	9.58	72.13	57.6	9	8.91	62.39	46.3	8.21	52.91	36.2	9
10	10.39	84.73	73.3	9.69	73.80	59.6	10	9.02	63.88	48.0	8.31	54.19	37.5	10
11	10.50	86.63	75.8	9.80	75.48	61.7	11	9.12	65.40	49.7	8.40	55.48	38.9	11
12	10.62	88.55	78.3	9.91	77.18	63.8	12	9.23	66.92	51.5	8.50	56.79	40.2	12
13	10.73	90.48	80.9	10.02	78.90	65.9	13	9.34	68.47	53.3	8.60	58.11	41.7	13
14	10.85	92.41	83.6	10.13	80.64	68.1	14	9.44	70.04	55.1	8.70	59.45	43.1	14
15	10.96	94.42	86.3	10.24	82.40	70.3	15	9.55	71.62	57.0	8.80	60.81	44.6	15
16	11.08	96.42	89.0	10.35	84.18	72.6	16	9.66	73.22	58.9	8.90	62.18	46.1	16
17	11.20	98.45	91.8	10.46	85.97	75.0	17	9.76	74.84	60.9	9.00	63.56	47.6	17
18	11.31	100.49	94.7	10.57	87.79	77.3	18	9.87	76.47	62.9	9.09	64.96	49.2	18
19	11.43	102.55	97.7	10.68	89.62	79.8	19	9.97	78.13	64.9	9.19	66.38	50.8	19
20	11.54	104.64	100.6	10.79	91.48	82.3	20	10.08	79.80	67.0	9.29	67.81	52.5	20
21	11.66	106.74	103.7	10.90	93.35	84.8	21	10.19	81.49	69.2	9.39	69.25	54.2	21
22	11.77	108.87	106.8	11.01	95.24	87.4	22	10.29	83.19	71.3	9.49	70.71	55.9	22
23	11.89	111.02	110.0	11.12	97.15	90.0	23	10.40	84.92	73.6	9.59	72.19	57.7	23
24	12.00	113.19	113.2	11.23	99.08	92.7	24	10.50	86.66	75.9	9.69	73.68	59.5	24
25	12.12	115.38	116.5	11.34	101.03	95.5	25	10.61	88.42	78.2	9.78	75.19	61.3	25
26	12.24	117.57	119.9	11.45	103.00	98.3	26	10.72	90.20	80.5	9.88	76.71	63.2	26
27	12.35	119.82	123.3	11.56	104.98	101.1	27	10.82	91.99	83.0	9.98	78.25	65.1	27
28	12.47	122.07	126.8	11.67	106.99	104.1	28	10.93	93.80	85.4	10.08	79.80	67.0	28
29	12.58	124.35	130.4	11.78	109.01	107.0	29	11.03	95.63	87.9	10.18	81.37	69.0	29
30	12.70	126.64	134.0	11.89	111.05	110.0	30	11.14	97.48	90.5	10.28	82.95	71.0	30
31	12.81	128.96	137.7	12.00	113.12	113.1	31	11.25	99.35	93.1	10.38	84.55	73.1	31
32	12.93	131.30	141.5	12.11	115.20	116.3	32	11.35	101.23	95.8	10.47	86.16	75.2	32
33	13.05	133.65	145.3	12.22	117.30	119.5	33	11.46	103.13	98.5	10.57	87.79	77.3	33
34	13.16	136.03	149.2	12.33	119.42	122.7	34	11.57	105.05	101.2	10.67	89.43	79.5	34
35	13.28	138.43	153.1	12.44	121.56	126.0	35	11.67	106.99	104.1	10.77	91.09	81.7	35
36	13.39	140.85	157.2	12.55	123.71	129.4	36	11.78	108.94	106.9	10.87	92.77	84.0	36
37	13.51	143.29	161.3	12.66	125.87	132.8	37	11.88	110.91	109.8	10.97	94.46	86.3	37
38	13.62	145.76	165.5	12.77	128.08	136.3	38	11.99	112.90	112.8	11.07	96.16	88.7	38
39	13.74	148.24	169.7	12.88	130.30	139.8	39	12.10	114.91	115.8	11.16	97.88	91.1	39
40	13.85	150.75	174.0	12.99	132.53	143.5	40	12.20	116.93	118.9	11.26	99.62	93.5	40
41	13.97	153.27	178.4	13.10	134.78	147.1	41	12.31	118.98	122.0	11.36	101.37	96.0	41
42	14.09	155.82	182.9	13.21	137.05	150.9	42	12.41	121.04	125.2	11.46	103.13	98.5	42
43	14.20	158.39	187.4	13.32	139.34	154.7	43	12.52	123.12	128.4	11.56	104.91	101.0	43
44	14.32	160.97	192.0	13.43	141.65	158.5	44	12.63	125.21	131.7	11.66	106.71	103.6	44
45	14.43	163.58	196.7	13.54	143.98	162.4	45	12.73	127.32	135.1	11.75	108.52	106.3	45
46	14.55	166.21	201.5	13.65	146.33	166.4	46	12.84	129.45	138.5	11.85	110.35	109.0	46
47	14.66	168.87	206.3	13.76	148.69	170.5	47	12.94	131.60	142.0	11.95	112.19	111.7	47
48	14.78	171.54	211.2	13.87	151.08	174.6	48	13.05	133.77	145.5	12.05	114.05	114.5	48
49	14.89	174.23	216.2	13.98	153.48	178.8	49	13.16	135.95	149.1	12.15	115.92	117.4	49
50	15.01	176.95	221.3	14.09	155.90	183.0	50	13.26	138.16	152.7	12.25	117.81	120.2	50

90'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.13	179.68	226.5	14.20	158.34	187.3	51	13.37	140.37	156.4	12.35	119.71	123.2	51
52	15.24	182.44	231.7	14.31	160.80	191.7	52	13.48	142.61	160.1	12.44	121.63	126.1	52
53	15.36	185.22	237.0	14.42	163.28	196.2	53	13.58	144.87	163.9	12.54	123.56	129.1	53
54	15.47	188.01	242.4	14.53	165.78	200.7	54	13.69	147.14	167.8	12.64	125.51	132.2	54
55	15.59	190.83	247.9	14.64	168.30	205.3	55	13.79	149.43	171.8	12.74	127.48	135.3	55
56	15.70	193.67	253.4	14.75	170.84	210.0	56	13.90	151.74	175.7	12.84	129.45	138.5	56
57	15.82	196.54	259.1	14.86	173.39	214.7	57	14.01	154.06	179.8	12.94	131.45	141.7	57
58	15.93	199.42	264.8	14.97	175.96	219.5	58	14.11	156.41	183.9	13.04	133.46	145.0	58
59	16.05	202.32	270.6	15.08	178.56	224.3	59	14.22	158.77	188.1	13.13	135.48	148.3	59
60	16.17	205.25	276.5	15.19	181.17	229.3	60	14.32	161.14	192.3	13.23	137.52	151.6	60
61	16.28	208.19	282.5	15.30	183.80	234.3	61	14.43	163.54	196.6	13.33	139.58	155.1	61
62	16.40	211.16	288.5	15.41	186.45	239.4	62	14.54	165.95	201.0	13.43	141.65	158.5	62
63	16.51	214.14	294.7	15.52	189.12	244.5	63	14.64	168.39	205.5	13.53	143.74	162.0	63
64	16.63	217.15	300.9	15.63	191.81	249.8	64	14.75	170.84	210.0	13.63	145.84	165.6	64
65	16.74	220.18	307.2	15.74	194.52	255.1	65	14.85	173.30	214.5	13.73	147.95	169.2	65
66	16.86	223.23	313.6	15.85	197.24	260.5	66	14.96	175.79	219.1	13.82	150.09	172.9	66
67	16.97	226.30	320.1	15.96	199.99	265.9	67	15.07	178.29	223.8	13.92	152.23	176.6	67
68	17.09	229.40	326.7	16.07	202.75	271.5	68	15.17	180.81	228.6	14.02	154.40	180.4	68
69	17.21	232.51	333.4	16.18	205.53	277.1	69	15.28	183.35	233.4	14.12	156.57	184.2	69
70	17.32	235.64	340.1	16.29	208.34	282.7	70	15.38	185.70	238.3	14.22	158.77	188.1	70
71	17.44	238.80	347.0	16.40	211.16	288.5	71	15.49	188.47	243.3	14.32	160.97	192.0	71
72	17.55	241.97	353.9	16.51	214.00	294.4	72	15.60	191.07	248.3	14.41	163.20	196.0	72
73	17.67	245.17	361.0	16.62	216.86	300.3	73	15.70	193.67	253.4	14.51	165.44	200.1	73
74	17.78	248.39	368.1	16.73	219.73	306.3	74	15.81	196.30	258.6	14.61	167.69	204.2	74
75	17.90	251.63	375.3	16.84	222.63	312.3	75	15.92	198.94	263.8	14.71	169.96	208.3	75
76	18.01	254.89	382.6	16.95	225.55	318.5	76	16.02	201.61	269.2	14.81	172.24	212.6	76
77	18.13	258.17	390.0	17.06	228.48	324.7	77	16.13	204.28	274.5	14.91	174.54	216.8	77
78	18.25	261.47	377.5	17.17	231.43	331.1	78	16.23	206.98	280.0	15.01	176.86	221.1	78
79	18.36	264.79	405.2	17.28	234.41	337.5	79	16.34	209.70	285.5	15.10	179.19	225.5	79
80	18.48	268.14	412.8	17.39	237.40	343.9	80	16.45	212.43	291.1	15.20	181.53	230.0	80
81	18.59	271.50	420.6	17.50	240.41	350.5	81	16.55	215.18	296.8	15.30	183.89	234.5	81
82	18.71	274.87	428.5	17.61	243.44	357.1	82	16.66	217.95	302.5	15.40	186.27	239.0	82
83	18.82	278.30	436.5	17.72	246.49	363.9	83	16.76	220.73	308.4	15.50	188.66	243.7	83
84	18.94	281.72	444.6	17.83	249.56	370.7	84	16.87	223.53	314.2	15.60	191.07	248.3	84
85	19.06	285.17	452.8	17.94	252.64	377.6	85	16.98	226.35	320.2	15.70	193.49	253.1	85
86	19.17	288.64	461.1	18.05	255.75	384.6	86	17.08	229.19	326.3	15.79	195.92	257.9	86
87	19.27	292.13	467.5	18.16	258.87	391.6	87	17.19	232.05	332.4	15.89	198.38	262.7	87
88	19.40	295.65	478.0	18.26	262.01	398.8	88	17.29	234.92	338.6	15.99	200.84	267.6	88
89	19.52	299.18	486.6	18.37	265.18	406.0	89	17.40	237.81	344.8	16.09	203.33	272.6	89
90	19.63	302.73	495.3	18.48	268.36	413.4	90	17.51	240.72	351.2	16.19	205.82	277.6	90

95'
8000 psi

95'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIAM. IN.	AREA SQ.IN.	MOM. FT K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.59	53.4	8.70	59.47	43.1	1	8.06	51.04	34.3	7.42	43.21	26.7	1
2	9.46	70.28	55.4	8.81	60.95	44.7	2	8.17	52.36	35.6	7.51	44.35	27.8	2
3	9.57	72.00	57.4	8.92	62.44	46.4	3	8.27	53.70	37.0	7.61	45.49	28.9	3
4	9.69	73.73	59.5	9.02	63.95	48.1	4	8.37	55.06	38.4	7.71	46.66	30.0	4
5	9.80	75.48	61.7	9.13	65.48	49.8	5	8.48	56.43	39.9	7.80	47.83	31.1	5
6	9.92	77.25	63.8	9.24	67.03	51.6	6	8.58	57.82	41.3	7.90	49.02	32.3	6
7	10.03	79.05	66.1	9.35	68.59	53.4	7	8.68	59.23	42.9	8.00	50.23	33.5	7
8	10.15	80.86	68.4	9.45	70.18	55.3	8	8.79	60.65	44.4	8.09	51.45	34.7	8
9	10.26	82.69	70.7	9.56	71.78	57.2	9	8.89	62.09	46.0	8.19	52.68	36.0	9
10	10.38	84.55	73.1	9.67	73.40	59.1	10	8.99	63.55	47.6	8.29	53.93	37.2	10
11	10.49	86.42	75.5	9.77	75.04	61.1	11	9.10	65.02	49.3	8.38	55.20	38.6	11
12	10.60	88.32	78.0	9.88	76.70	63.2	12	9.20	66.51	51.0	8.48	56.48	39.9	12
13	10.72	90.24	80.6	9.99	78.37	65.3	13	9.31	68.02	52.7	8.58	57.77	41.3	13
14	10.83	92.17	83.2	10.10	80.06	67.4	14	9.41	69.54	54.5	8.67	59.08	42.7	14
15	10.95	94.13	85.9	10.20	81.77	69.5	15	9.51	71.08	56.4	8.77	60.40	44.1	15
16	11.06	96.11	88.6	10.31	83.50	71.7	16	9.62	72.64	58.2	8.87	61.74	45.6	16
17	11.18	98.11	91.4	10.42	85.25	74.0	17	9.72	74.22	60.1	8.96	63.09	47.1	17
18	11.29	100.13	94.2	10.53	87.01	76.3	18	9.82	75.81	62.1	9.06	64.46	48.7	18
19	11.41	102.17	97.1	10.63	88.80	78.7	19	9.93	77.42	64.1	9.16	65.84	50.2	19
20	11.52	104.23	100.1	10.74	90.60	81.1	20	10.03	79.05	66.1	9.25	67.24	51.8	20
21	11.63	106.31	103.1	10.85	92.42	83.5	21	10.14	80.69	68.2	9.35	68.65	53.5	21
22	11.75	108.41	106.1	10.95	94.26	86.0	22	10.24	82.35	70.3	9.45	70.07	55.2	22
23	11.86	110.54	109.3	11.06	96.11	88.6	23	10.34	84.02	72.4	9.54	71.51	56.9	23
24	11.98	112.68	112.5	11.17	97.98	91.2	24	10.45	85.72	74.6	9.64	72.97	58.6	24
25	12.09	114.84	115.7	11.28	99.88	93.9	25	10.55	87.43	76.9	9.74	74.44	60.4	25
26	12.21	117.03	119.0	11.38	101.78	96.6	26	10.65	89.16	79.2	9.83	75.92	62.2	26
27	12.32	119.23	122.4	11.49	103.71	99.3	27	10.76	90.90	81.5	9.93	77.42	64.1	27
28	12.44	121.46	125.9	11.60	105.66	102.1	28	10.86	92.66	83.7	10.02	78.93	65.9	28
29	12.55	123.70	129.4	11.71	107.62	105.0	29	10.97	94.44	86.3	10.12	80.46	67.9	29
30	12.66	125.97	132.9	11.81	109.60	107.9	30	11.07	96.23	88.8	10.22	82.00	69.8	30
31	12.78	128.26	136.6	11.92	111.60	110.9	31	11.17	98.05	91.3	10.31	83.56	71.8	31
32	12.89	130.56	140.3	12.03	113.62	113.9	32	11.28	99.88	93.9	10.41	85.13	73.9	32
33	13.01	132.89	144.0	12.14	115.66	117.0	33	11.38	101.72	96.5	10.51	86.72	75.9	33
34	13.12	135.24	147.9	12.24	117.71	120.1	34	11.48	103.58	99.1	10.60	88.32	78.0	34
35	13.24	137.61	151.8	12.35	119.79	123.3	35	11.59	105.46	101.8	10.70	89.94	80.2	35
36	13.35	140.00	155.8	12.46	121.88	126.5	36	11.69	107.36	104.6	10.80	91.57	82.4	36
37	13.47	142.41	159.8	12.56	123.98	129.8	37	11.80	109.27	107.4	10.89	93.21	84.6	37
38	13.58	144.84	163.9	12.67	126.11	133.2	38	11.90	111.20	110.3	10.99	94.87	86.9	38
39	13.69	147.29	168.1	12.78	128.26	136.6	39	12.00	113.15	113.2	11.09	96.55	89.2	39
40	13.81	149.76	172.3	12.89	130.42	140.0	40	12.11	115.11	116.1	11.18	98.24	91.5	40
41	13.92	152.26	176.7	12.99	132.60	143.6	41	12.21	117.09	119.1	11.28	99.94	93.9	41
42	14.04	154.77	181.0	13.10	134.80	147.2	42	12.31	119.09	122.2	11.38	101.66	96.4	42
43	14.15	157.31	185.5	13.21	137.02	150.8	43	12.42	121.11	125.3	11.47	103.39	98.8	43
44	14.27	159.86	190.0	13.32	139.25	154.5	44	12.52	123.14	128.5	11.57	105.14	101.4	44
45	14.38	162.43	194.7	13.42	141.50	158.3	45	12.63	125.19	131.7	11.67	106.90	103.9	45
46	14.50	165.03	199.3	13.53	143.77	162.1	46	12.73	127.25	135.0	11.76	108.68	106.5	46
47	14.61	167.65	204.1	13.64	146.06	166.0	47	12.83	129.33	138.3	11.86	110.47	109.2	47
48	14.72	170.28	208.9	13.74	148.37	169.9	48	12.94	131.43	141.7	11.96	112.28	111.9	48
49	14.84	172.94	213.8	13.85	150.70	173.9	49	13.04	133.55	145.1	12.05	114.10	114.6	49
50	14.95	175.62	218.8	13.96	153.04	178.0	50	13.14	135.68	148.6	12.15	115.93	117.4	50

95'
8000 psi

95'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.35	68.59	53.4	8.70	59.47	43.1	1	8.06	51.04	34.3	7.42	43.21	26.7	1
2	9.46	70.28	55.4	8.81	60.95	44.7	2	8.17	52.36	35.6	7.51	44.35	27.8	2
3	9.57	72.00	57.4	8.92	62.44	46.4	3	8.27	53.70	37.0	7.61	45.49	28.9	3
4	9.69	73.73	59.5	9.02	63.95	48.1	4	8.37	55.06	38.4	7.71	46.66	30.0	4
5	9.80	75.48	61.7	9.13	65.48	49.8	5	8.48	56.43	39.9	7.80	47.83	31.1	5
6	9.92	77.25	63.8	9.24	67.03	51.6	6	8.58	57.82	41.3	7.90	49.02	32.3	6
7	10.03	79.05	66.1	9.35	68.59	53.4	7	8.68	59.23	42.9	8.00	50.23	33.5	7
8	10.15	80.86	68.4	9.45	70.18	55.3	8	8.79	60.65	44.4	8.09	51.45	34.7	8
9	10.26	82.69	70.7	9.56	71.78	57.2	9	8.89	62.09	46.0	8.19	52.68	36.0	9
10	10.38	84.55	73.1	9.67	73.40	59.1	10	8.99	63.55	47.6	8.29	53.93	37.2	10
11	10.49	86.42	75.5	9.77	75.04	61.1	11	9.10	65.02	49.3	8.38	55.20	38.6	11
12	10.60	88.32	78.0	9.88	76.70	63.2	12	9.20	66.51	51.0	8.48	56.48	39.9	12
13	10.72	90.24	80.6	9.99	78.37	65.2	13	9.31	68.02	52.7	8.58	57.77	41.3	13
14	10.83	92.17	83.2	10.10	80.06	67.4	14	9.41	69.54	54.5	8.67	59.08	42.7	14
15	10.95	94.13	85.9	10.20	81.77	69.5	15	9.51	71.08	56.4	8.77	60.40	44.1	15
16	11.06	96.11	88.6	10.31	83.50	71.7	16	9.62	72.64	58.2	8.87	61.74	45.6	16
17	11.18	98.11	91.4	10.42	85.25	74.0	17	9.72	74.22	60.1	8.96	63.09	47.1	17
18	11.29	100.13	94.2	10.53	87.01	76.3	18	9.82	75.81	62.1	9.06	64.46	48.7	18
19	11.41	102.17	97.1	10.63	88.80	78.7	19	9.93	77.42	64.1	9.16	65.84	50.2	19
20	11.52	104.23	100.1	10.74	90.60	81.1	20	10.03	79.05	66.1	9.25	67.24	51.8	20
21	11.63	106.31	103.1	10.85	92.42	83.5	21	10.14	80.69	68.2	9.35	68.65	53.5	21
22	11.75	108.41	106.1	10.95	94.26	86.0	22	10.24	82.35	70.3	9.45	70.07	55.2	22
23	11.86	110.54	109.3	11.06	96.11	88.6	23	10.34	84.02	72.4	9.54	71.51	56.9	23
24	11.98	112.68	112.5	11.17	97.98	91.2	24	10.45	85.72	74.6	9.64	72.97	58.6	24
25	12.09	114.84	115.7	11.28	99.88	93.9	25	10.55	87.43	76.9	9.74	74.44	60.4	25
26	12.21	117.03	119.0	11.38	101.78	96.6	26	10.65	89.14	79.2	9.83	75.92	62.2	26
27	12.32	119.23	122.4	11.49	103.71	99.3	27	10.76	90.90	81.5	9.93	77.42	64.1	27
28	12.44	121.46	125.9	11.60	105.66	102.1	28	10.86	92.66	83.9	10.02	78.93	65.9	28
29	12.55	123.70	129.4	11.71	107.62	105.0	29	10.97	94.44	86.3	10.12	80.46	67.9	29
30	12.66	125.97	132.9	11.81	109.60	107.9	30	11.07	96.23	88.8	10.22	82.00	69.8	30
31	12.78	128.26	136.6	11.92	111.60	110.9	31	11.17	98.05	91.3	10.31	83.56	71.8	31
32	12.89	130.56	140.3	12.03	113.62	113.9	32	11.28	99.88	93.9	10.41	85.13	73.9	32
33	13.01	132.89	144.0	12.14	115.66	117.0	33	11.38	101.72	96.5	10.51	86.72	75.9	33
34	13.12	135.24	147.9	12.24	117.71	120.1	34	11.48	103.58	99.1	10.60	88.32	78.0	34
35	13.24	137.61	151.8	12.35	119.79	123.3	35	11.59	105.46	101.8	10.70	89.94	80.2	35
36	13.35	140.00	155.8	12.46	121.88	126.5	36	11.69	107.36	104.6	10.80	91.57	82.4	36
37	13.47	142.41	159.8	12.56	123.98	129.8	37	11.80	109.27	107.4	10.89	93.21	84.6	37
38	13.58	144.84	163.9	12.67	126.11	133.2	38	11.90	111.20	110.3	10.99	94.87	86.9	38
39	13.69	147.29	168.1	12.78	128.26	136.6	39	12.00	113.15	113.2	11.09	96.55	89.2	39
40	13.81	149.76	172.3	12.89	130.42	140.0	40	12.11	115.11	116.1	11.18	98.24	91.5	40
41	13.92	152.26	176.7	12.99	132.60	143.6	41	12.21	117.09	119.1	11.28	99.94	93.9	41
42	14.04	154.77	181.0	13.10	134.80	147.2	42	12.31	119.09	122.2	11.38	101.66	96.4	42
43	14.15	157.31	185.5	13.21	137.02	150.8	43	12.42	121.11	125.3	11.47	103.39	98.8	43
44	14.27	159.86	190.0	13.32	139.25	154.5	44	12.52	123.14	128.5	11.57	105.14	101.4	44
45	14.38	162.43	194.7	13.42	141.50	158.3	45	12.63	125.19	131.7	11.67	106.90	103.9	45
46	14.50	165.03	199.3	13.53	143.77	162.1	46	12.73	127.25	135.0	11.76	108.68	106.5	46
47	14.61	167.65	204.1	13.64	146.06	166.0	47	12.83	129.33	138.3	11.86	110.47	109.2	47
48	14.72	170.28	208.9	13.74	148.37	169.9	48	12.94	131.43	141.7	11.96	112.28	111.9	48
49	14.84	172.94	213.8	13.85	150.70	173.9	49	13.04	133.55	145.1	12.05	114.10	114.6	49
50	14.95	175.62	218.8	13.96	153.04	178.0	50	13.14	135.68	148.6	12.15	115.93	117.4	50

95'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	15.07	178.32	223.9	14.07	155.40	182.2	51	13.25	137.83	152.2	12.25	117.78	120.2	51
52	15.18	181.04	229.0	14.17	157.78	186.4	52	13.35	140.00	155.8	12.34	119.65	123.1	52
53	15.30	183.78	234.3	14.28	160.18	190.6	53	13.45	142.18	159.4	12.44	121.53	126.0	53
54	15.41	186.54	239.6	14.39	162.60	194.9	54	13.56	144.38	163.1	12.54	123.42	128.9	54
55	15.53	189.32	244.9	14.50	165.03	199.3	55	13.66	146.60	166.9	12.63	125.33	131.9	55
56	15.64	192.12	250.4	14.60	167.48	203.8	56	13.77	148.84	170.7	12.73	127.25	135.0	56
57	15.75	194.94	255.9	14.71	169.95	208.3	57	13.87	151.09	174.6	12.83	129.19	138.1	57
58	15.87	197.78	261.5	14.82	172.44	212.9	58	13.97	153.35	178.6	12.92	131.14	141.2	58
59	15.98	200.65	267.2	14.92	174.95	217.6	59	14.08	155.64	182.6	13.02	133.11	144.4	59
60	16.10	203.53	273.0	15.03	177.47	222.3	60	14.18	157.94	186.6	13.12	135.09	147.6	60
61	16.21	206.43	278.9	15.14	180.01	227.1	61	14.28	160.26	190.8	13.21	137.09	150.9	61
62	16.33	209.36	284.8	15.25	182.57	232.0	62	14.39	162.60	194.9	13.31	139.10	154.3	62
63	16.44	212.30	290.9	15.35	185.15	236.9	63	14.49	164.95	199.2	13.40	141.13	157.6	63
64	16.56	215.27	277.0	15.46	187.75	241.9	64	14.60	167.32	203.5	13.50	143.17	161.1	64
65	16.67	218.26	303.2	15.57	190.37	247.0	65	14.70	169.70	207.9	13.60	145.22	164.6	65
66	16.78	221.26	309.5	15.68	193.00	252.1	66	14.80	172.11	212.3	13.69	147.29	168.1	66
67	16.90	224.29	315.8	15.78	195.65	257.3	67	14.91	174.53	216.8	13.79	149.38	171.7	67
68	17.01	227.34	322.3	15.89	198.32	262.6	68	15.01	176.97	221.4	13.89	151.48	175.3	68
69	17.13	230.41	328.9	16.00	201.01	268.0	69	15.11	179.42	226.0	13.98	153.59	179.0	69
70	17.24	233.50	335.5	16.11	203.71	273.4	70	15.22	181.89	230.7	14.08	155.72	182.7	70
71	17.36	236.61	342.2	16.21	206.43	278.9	71	15.32	184.38	235.4	14.18	157.86	186.5	71
72	17.47	239.74	349.0	16.32	209.18	284.5	72	15.43	186.88	240.2	14.27	160.02	190.3	72
73	17.59	242.89	355.9	16.43	211.94	290.1	73	15.53	189.40	245.1	14.37	162.19	194.2	73
74	17.70	246.06	362.9	16.53	214.71	295.8	74	15.63	191.94	250.0	14.47	164.38	198.2	74
75	17.81	249.25	370.0	16.64	217.51	301.6	75	15.74	194.50	255.1	14.56	166.58	202.2	75
76	17.93	252.47	377.2	16.75	220.32	307.5	76	15.84	197.07	260.1	14.66	168.80	206.2	76
77	18.04	255.70	384.5	16.86	223.15	313.4	77	15.94	199.66	265.3	14.76	171.03	210.3	77
78	18.16	258.96	391.8	16.96	226.00	319.5	78	16.05	202.27	270.5	14.85	173.27	214.5	78
79	18.27	262.23	399.3	17.07	228.87	325.6	79	16.15	204.89	275.8	14.95	175.53	218.7	79
80	18.39	265.53	406.8	17.18	231.76	331.7	80	16.26	207.53	281.1	15.05	177.81	222.9	80
81	18.50	268.84	414.5	17.29	234.66	338.0	81	16.36	210.19	286.5	15.14	180.10	227.3	81
82	18.62	272.18	422.2	17.39	237.59	344.3	82	16.46	212.86	292.0	15.24	182.40	231.6	82
83	18.73	275.53	430.0	17.50	240.53	350.7	83	16.57	215.55	297.6	15.34	184.72	236.1	83
84	18.84	278.91	438.0	17.61	243.48	357.2	84	16.67	218.26	303.2	15.43	187.06	240.6	84
85	18.96	282.31	446.0	17.71	246.46	363.8	85	16.77	220.98	308.9	15.53	189.40	245.1	85
86	19.07	285.73	454.1	17.82	249.46	370.5	86	16.88	223.72	314.6	15.63	191.77	249.7	86
87	19.19	289.17	462.4	17.93	252.47	377.2	87	16.98	226.48	320.5	15.72	194.14	254.4	87
88	19.30	292.63	470.7	18.04	255.50	384.0	88	17.09	229.26	326.4	15.82	196.54	259.1	88
89	17.42	296.11	477.1	18.14	258.55	390.9	89	17.19	232.05	332.4	15.92	198.94	263.8	89
90	19.53	299.61	487.6	18.25	261.61	397.9	90	17.29	234.86	338.4	16.01	201.37	268.7	90
91	17.65	303.13	496.2	18.36	264.70	404.9	91	17.40	237.68	344.5	16.11	203.80	273.6	91
92	19.76	306.67	505.0	18.47	267.80	412.1	92	17.50	240.53	350.7	16.21	206.25	278.5	92
93	19.87	310.24	513.8	18.57	270.92	419.3	93	17.60	243.38	357.0	16.30	208.72	283.5	93
94	19.99	313.82	522.7	18.68	274.06	426.6	94	17.71	246.26	363.4	16.40	211.20	288.6	94
95	20.10	317.42	531.8	18.79	277.22	434.0	95	17.81	249.15	369.8	16.49	213.69	293.7	95

100'
8000 psi

100'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
0	9.23	66.92	51.5	8.59	58.01	41.5	0	7.96	49.74	33.0	7.32	42.10	25.7	0
1	9.34	68.55	53.4	8.70	59.46	43.1	1	8.06	51.01	34.3	7.41	43.15	26.7	1
2	9.45	70.20	55.3	8.81	60.93	44.7	2	8.16	52.31	35.6	7.50	44.23	27.7	2
3	9.57	71.87	57.3	8.91	62.41	46.4	3	8.26	53.62	36.9	7.60	45.31	28.7	3
4	9.68	73.56	59.3	9.02	63.92	48.0	4	8.36	54.95	38.3	7.69	46.41	29.7	4
5	9.79	75.27	61.4	9.13	65.44	49.8	5	8.47	56.29	39.7	7.78	47.52	30.8	5
6	9.90	77.00	63.5	9.23	66.97	51.5	6	8.57	57.65	41.2	7.87	48.64	31.9	6
7	10.01	78.75	65.7	9.34	68.53	53.3	7	8.67	59.02	42.6	7.96	49.78	33.0	7
8	10.12	80.52	67.9	9.45	70.10	55.2	8	8.77	60.41	44.2	8.05	50.93	34.2	8
9	10.24	82.30	70.2	9.55	71.70	57.1	9	8.87	61.82	45.7	8.14	52.09	35.4	9
10	10.35	84.11	72.5	9.66	73.31	59.0	10	8.97	63.25	47.3	8.24	53.27	36.6	10
11	10.46	85.94	74.9	9.77	74.93	61.0	11	9.08	64.69	48.9	8.33	54.46	37.8	11
12	10.57	87.78	77.3	9.87	76.58	63.0	12	9.18	66.14	50.6	8.42	55.66	39.0	12
13	10.68	89.65	79.8	9.98	78.24	65.1	13	9.28	67.61	52.3	8.51	56.87	40.3	13
14	10.80	91.53	82.3	10.09	79.92	67.2	14	9.38	69.10	54.0	8.60	58.10	41.6	14
15	10.91	93.44	84.9	10.19	81.62	69.3	15	9.48	70.61	55.8	8.69	59.35	43.0	15
16	11.02	95.36	87.6	10.30	83.34	71.5	16	9.58	72.13	57.6	8.78	60.60	44.4	16
17	11.13	97.30	90.3	10.41	85.07	73.8	17	9.68	73.67	59.5	8.88	61.87	45.8	17
18	11.24	99.27	93.0	10.51	86.83	76.1	18	9.79	75.22	61.3	8.97	63.15	47.2	18
19	11.35	101.25	95.8	10.62	88.60	78.4	19	9.89	76.79	63.3	9.06	64.44	48.6	19
20	11.47	103.25	98.7	10.73	90.39	80.8	20	9.99	78.38	65.2	9.15	65.75	50.1	20
21	11.58	105.28	101.6	10.83	92.19	83.2	21	10.09	79.98	67.3	9.24	67.07	51.6	21
22	11.69	107.32	104.5	10.94	94.02	85.7	22	10.19	81.60	69.3	9.33	68.41	53.2	22
23	11.80	109.38	107.6	11.05	95.86	88.2	23	10.29	83.23	71.4	9.42	69.75	54.8	23
24	11.91	111.46	110.6	11.15	97.72	90.8	24	10.40	84.88	73.5	9.52	71.11	56.4	24
25	12.02	113.56	113.8	11.26	99.60	93.5	25	10.50	86.55	75.7	9.61	72.49	58.0	25
26	12.14	115.68	117.0	11.37	101.49	96.1	26	10.60	88.23	77.9	9.70	73.87	59.7	26
27	12.25	117.82	120.3	11.47	103.41	98.9	27	10.70	89.93	80.2	9.79	75.27	61.4	27
28	12.36	119.98	123.6	11.58	105.34	101.7	28	10.80	91.65	82.5	9.88	76.68	63.1	28
29	12.47	122.16	127.0	11.69	107.29	104.5	29	10.90	93.38	84.8	9.97	78.11	64.9	29
30	12.58	124.36	130.4	11.79	109.26	107.4	30	11.01	95.13	87.2	10.06	79.55	66.7	30
31	12.70	126.58	133.7	11.90	111.24	110.3	31	11.11	96.89	89.7	10.16	81.00	68.5	31
32	12.81	128.82	137.5	12.01	113.24	113.3	32	11.21	98.67	92.2	10.25	82.47	70.4	32
33	12.92	131.08	141.1	12.11	115.26	116.4	33	11.31	100.47	94.7	10.34	83.94	72.3	33
34	13.03	133.35	144.8	12.22	117.30	119.5	34	11.41	102.28	97.3	10.43	85.44	74.3	34
35	13.14	135.65	148.6	12.33	119.36	122.6	35	11.51	104.11	99.9	10.52	86.94	76.2	35
36	13.25	137.97	152.4	12.43	121.43	125.8	36	11.61	105.96	102.6	10.61	88.46	78.2	36
37	13.37	140.30	156.3	12.54	123.53	129.1	37	11.72	107.82	105.3	10.70	89.99	80.3	37
38	13.48	142.66	160.2	12.65	125.64	132.4	38	11.82	109.69	108.0	10.80	91.53	82.3	38
39	13.59	145.04	164.2	12.75	127.76	135.8	39	11.92	111.59	110.8	10.89	93.09	84.4	39
40	13.70	147.43	168.3	12.86	129.91	139.2	40	12.02	113.50	113.7	10.98	94.66	86.6	40
41	13.81	149.84	172.5	12.97	132.07	142.7	41	12.12	115.43	116.6	11.07	96.24	88.8	41
42	13.92	152.28	176.7	13.07	134.26	146.3	42	12.22	117.37	119.6	11.16	97.84	91.0	42
43	14.04	154.73	181.0	13.18	136.46	149.9	43	12.33	119.33	122.6	11.25	99.45	93.2	43
44	14.15	157.21	185.3	13.29	138.67	153.5	44	12.43	121.30	125.6	11.34	101.07	95.5	44
45	14.26	159.70	189.8	13.39	140.91	157.3	45	12.53	123.29	128.7	11.44	102.71	97.9	45
46	14.37	162.21	194.3	13.50	143.16	161.1	46	12.63	125.30	131.9	11.53	104.36	100.2	46
47	14.48	164.75	198.8	13.61	145.43	164.9	47	12.73	127.32	135.1	11.62	106.02	102.6	47
48	14.59	167.30	203.5	13.71	147.72	168.8	48	12.83	129.36	138.3	11.71	107.69	105.1	48
49	14.71	169.87	208.2	13.82	150.03	172.8	49	12.94	131.42	141.7	11.80	109.38	107.6	49
50	14.82	172.46	213.0	13.93	152.35	176.8	50	13.04	133.49	145.0	11.89	111.08	110.1	50

100'
8000 psi

DOUGLAS FIR AND SOUTHERN YELLOW PINE
Ultimate Bending Stress - 8000 psi

	CL H-1			CL 1				CL 2			CL 3			
DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIAM. IN.	AREA SQ.IN.	MOM. FT-K	DIST. FT.
51	14.93	175.07	217.8	14.03	154.70	180.9	51	13.14	135.58	148.4	11.98	112.80	112.6	51
52	15.04	177.70	222.7	14.14	157.06	185.1	52	13.24	137.69	151.9	12.08	114.52	115.2	52
53	15.15	180.35	227.7	14.25	159.43	189.3	53	13.34	139.81	155.4	12.17	116.27	117.9	53
54	15.27	183.02	232.8	14.35	161.83	193.6	54	13.44	141.94	159.0	12.26	118.02	120.6	54
55	15.38	185.71	238.0	14.46	164.25	197.9	55	13.55	144.10	162.6	12.35	119.79	123.3	55
56	15.49	188.42	243.2	14.57	166.68	202.3	56	13.65	146.27	166.3	12.44	121.57	126.0	56
57	15.60	191.15	248.5	14.67	169.13	206.8	57	13.75	148.45	170.1	12.53	123.36	128.8	57
58	15.71	193.90	253.9	14.78	171.59	211.4	58	13.85	150.65	173.9	12.62	125.17	131.7	58
59	15.82	196.66	259.3	14.89	174.08	216.0	59	13.95	152.87	177.7	12.72	126.99	134.6	59
60	15.94	199.45	264.9	14.99	176.58	220.6	60	14.05	155.11	181.6	12.81	128.82	137.5	60
61	16.05	202.26	270.5	15.10	179.10	225.4	61	14.15	157.36	185.6	12.90	130.66	140.4	61
62	16.16	205.09	276.2	15.21	181.64	230.2	62	14.26	159.62	189.6	12.99	132.52	143.4	62
63	16.27	207.93	281.9	15.31	184.20	235.1	63	14.36	161.91	193.7	13.08	134.40	146.5	63
64	16.38	210.80	287.8	15.42	186.78	240.0	64	14.46	164.21	197.9	13.17	136.28	149.6	64
65	16.49	213.68	293.7	15.53	189.37	245.0	65	14.56	166.52	202.1	13.26	138.18	152.7	65
66	16.61	216.59	299.7	15.63	191.98	250.1	66	14.66	168.85	206.3	13.36	140.09	155.9	66
67	16.72	219.51	305.8	15.74	194.61	255.3	67	14.76	171.20	210.6	13.45	142.02	159.1	67
68	16.83	222.46	312.0	15.85	197.25	260.5	68	14.87	173.57	215.0	13.54	143.95	162.4	68
69	16.94	225.42	318.2	15.95	199.92	265.8	69	14.97	175.95	219.4	13.63	145.90	165.7	69
70	17.05	228.41	324.6	16.06	202.60	271.2	70	15.07	178.34	223.9	13.72	147.87	169.1	70
71	17.17	231.41	331.0	16.17	205.30	276.6	71	15.17	180.76	228.5	13.81	149.84	172.5	71
72	17.28	234.43	337.5	16.27	208.02	282.1	72	15.27	183.18	233.1	13.90	151.84	175.9	72
73	17.39	237.47	344.1	16.38	210.75	287.7	73	15.37	185.63	237.8	14.00	153.84	179.4	73
74	17.50	240.54	350.8	16.49	213.51	293.3	74	15.48	188.09	242.6	14.09	155.86	183.0	74
75	17.61	243.62	357.5	16.59	216.28	299.1	75	15.58	190.57	247.4	14.18	157.88	186.5	75
76	17.72	246.72	364.4	16.70	219.07	304.9	76	15.68	193.06	252.2	14.27	159.93	190.2	76
77	17.84	249.84	371.3	16.81	221.88	310.8	77	15.78	195.57	257.2	14.36	161.98	193.8	77
78	17.95	252.98	378.3	16.91	224.70	316.7	78	15.88	198.10	262.2	14.45	164.05	197.6	78
79	18.06	256.14	385.5	17.02	227.54	322.7	79	15.98	200.64	267.2	14.54	166.13	201.3	79
80	18.17	259.32	392.7	17.13	230.41	328.8	80	16.08	203.20	272.4	14.64	168.23	205.2	80
81	18.28	262.52	399.9	17.23	233.28	335.0	81	16.19	205.77	277.5	14.73	170.34	209.0	81
82	18.39	265.74	407.3	17.34	236.18	341.3	82	16.29	208.37	282.8	14.82	172.46	213.0	82
83	18.51	268.98	414.8	17.45	239.10	347.6	83	16.39	210.97	288.1	14.91	174.60	216.9	83
84	18.62	272.24	422.3	17.55	242.03	354.0	84	16.49	213.60	293.5	15.00	176.74	220.9	84
85	18.73	275.51	430.0	17.66	244.98	360.5	85	16.59	216.24	299.0	15.09	178.90	225.0	85
86	18.84	278.81	437.7	17.77	247.95	367.1	86	16.69	218.89	304.5	15.18	181.08	229.1	86
87	18.95	282.13	445.6	17.87	250.93	373.8	87	16.80	221.56	310.1	15.28	183.27	233.3	87
88	19.06	285.46	453.5	17.98	253.94	380.5	88	16.90	224.25	315.8	15.37	185.47	237.5	88
89	19.18	288.82	461.5	18.07	256.96	387.3	89	17.00	226.96	321.5	15.46	187.68	241.8	89
90	19.29	292.20	469.6	18.17	260.00	394.2	90	17.10	229.68	327.3	15.55	189.91	246.1	90
91	19.40	295.59	477.9	18.30	263.05	401.2	91	17.20	232.41	333.2	15.64	192.15	250.4	91
92	19.51	299.01	486.2	18.41	266.13	408.2	92	17.30	235.17	339.1	15.73	194.40	254.9	92
93	19.62	302.44	494.6	18.51	269.22	415.4	93	17.41	237.94	345.1	15.82	196.66	259.3	93
94	19.74	305.90	503.1	18.62	272.33	422.6	94	17.51	240.72	351.2	15.92	198.94	263.8	94
95	19.85	309.37	511.6	18.73	275.46	429.9	95	17.61	243.52	357.3	16.01	201.24	268.4	95
96	19.96	312.86	520.3	18.83	278.61	437.3	96	17.71	246.34	363.5	16.10	203.54	273.0	96
97	20.07	316.38	529.1	18.94	281.77	444.7	97	17.81	249.18	369.8	16.19	205.86	277.7	97
98	20.18	317.91	538.0	19.05	284.96	452.3	98	17.91	252.03	376.2	16.28	208.19	282.5	98
99	20.29	323.46	547.0	19.15	288.16	459.9	99	18.02	254.89	382.6	16.37	210.54	287.2	99
100	20.41	327.03	556.1	19.26	291.38	467.7	100	18.12	257.78	389.1	16.46	212.89	292.1	100

Moment Reduction Due to a Bolt Hole in a Pole

The reduction in moment capacity of a pole caused by a bolt hole is calculated by the equation:

$$M_{bh} = \frac{(F_b)(b)(b^2\sin^2\theta + d_n{}^2\cos^2\theta)}{72(1000)}$$

where:

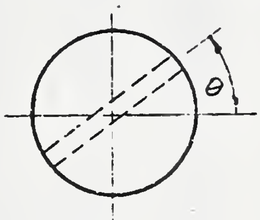
F_b = ultimate fiber stress of the wood (psi)
d_n = pole diameter at location 'n' (inches)
b = width of hole, taken as bolt diameter plus 1/16 inch (inches)
M_{bh} = reduction in strength (ft-kips)

The drawings below explain the table which follows:

$\theta = 0^o$

N.A.

$\theta = \text{Sin}^{-1}(3.5/d_n)$



N.A.

POLE MOMENT (FT-K) REDUCTION
DUE TO BOLT HOLES* (8000 psi wood)

POLE DIAM	3/4" 0 DEGREES	3/4" THETA	7/8" 0 DEGREES	7/8" THETA	1" 0 DEGREES	1" THETA
9.0	7.3	6.2	8.4	7.2	9.6	8.1
9.1	7.5	6.4	8.6	7.4	9.8	8.3
9.2	7.6	6.5	8.8	7.6	10.0	8.6
9.3	7.8	6.7	9.0	7.7	10.2	8.8
9.4	8.0	6.9	9.2	7.9	10.4	9.0
9.5	8.1	7.0	9.4	8.1	10.7	9.2
9.6	8.3	7.2	9.6	8.3	10.9	9.4
9.7	8.5	7.4	9.8	8.5	11.1	9.7
9.8	8.7	7.6	10.0	8.7	11.3	9.9
9.9	8.8	7.7	10.2	8.9	11.6	10.1
10.0	9.0	7.9	10.4	9.1	11.8	10.4
10.1	9.2	8.1	10.6	9.4	12.0	10.6
10.2	9.4	8.3	10.8	9.6	12.3	10.8
10.3	9.6	8.5	11.1	9.8	12.5	11.1
10.4	9.8	8.7	11.3	10.0	12.8	11.3
10.5	10.0	8.9	11.5	10.2	13.0	11.6
10.6	10.1	9.0	11.7	10.4	13.3	11.8
10.7	10.3	9.2	11.9	10.7	13.5	12.1
10.8	10.5	9.4	12.2	10.9	13.8	12.3
10.9	10.7	9.6	12.4	11.1	14.0	12.6
11.0	10.9	9.8	12.6	11.3	14.3	12.8
11.1	11.1	10.0	12.8	11.6	14.5	13.1
11.2	11.3	10.2	13.1	11.8	14.8	13.4
11.3	11.5	10.4	13.3	12.0	15.1	13.6
11.4	11.7	10.6	13.5	12.3	15.3	13.9
11.5	11.9	10.8	13.8	12.5	15.6	14.2
11.6	12.1	11.0	14.0	12.7	15.9	14.4
11.7	12.4	11.3	14.3	13.0	16.2	14.7
11.8	12.6	11.5	14.5	13.2	16.4	15.0
11.9	12.8	11.7	14.8	13.5	16.7	15.3
12.0	13.0	11.9	15.0	13.7	17.0	15.6
12.1	13.2	12.1	15.3	14.0	17.3	15.8
12.2	13.4	12.3	15.5	14.2	17.6	16.1
12.3	13.7	12.6	15.8	14.5	17.9	16.4
12.4	13.9	12.8	16.0	14.7	18.2	16.7
12.5	14.1	13.0	16.3	15.0	18.4	17.0
12.6	14.3	13.2	16.5	15.3	18.7	17.3
12.7	14.6	13.5	16.8	15.5	19.0	17.6
12.8	14.8	13.7	17.1	15.8	19.3	17.9
12.9	15.0	13.9	17.3	16.1	19.6	18.2
13.0	15.3	14.2	17.6	16.3	20.0	18.5
13.1	15.5	14.4	17.9	16.6	20.3	18.8
13.2	15.7	14.6	18.2	16.9	20.6	19.1
13.3	16.0	14.9	18.4	17.2	20.9	19.4
13.4	16.2	15.1	18.7	17.4	21.2	19.8
13.5	16.5	15.4	19.0	17.7	21.5	20.1
13.6	16.7	15.6	19.3	18.0	21.8	20.4
13.7	16.9	15.8	19.6	18.3	22.2	20.7
13.8	17.2	16.1	19.8	18.6	22.5	21.0
13.9	17.4	16.3	20.1	18.9	22.8	21.4
14.0	17.7	16.6	20.4	19.1	23.1	21.7
14.1	17.9	16.8	20.7	19.4	23.5	22.0
14.2	18.2	17.1	21.0	19.7	23.8	22.4
14.3	18.5	17.4	21.3	20.0	24.1	22.7
14.4	18.7	17.6	21.6	20.3	24.5	23.0
14.5	19.0	17.9	21.9	20.6	24.8	23.4
14.6	19.2	18.1	22.2	20.9	25.2	23.7
14.7	19.5	18.4	22.5	21.2	25.5	24.1
14.8	19.8	18.7	22.8	21.5	25.9	24.4
14.9	20.0	18.9	23.1	21.9	26.2	24.8

*Bolt Hole = Bolt diameter +1/16".

Pole Classes

Wood poles are separated into 15 classes based on the minimum circumference of the pole 6 feet from the butt. The minimum circumferences have been calculated in order for each species in a given class to develop at the groundline stresses approximately equal to those shown in the table when a horizontal load is applied 2 feet from the top of the pole. The horizontal loads used in these calculations are as follows:

Class	Horizontal Load (Pounds)	Class	Horizontal Load (Pounds)
H6	11,400	4	2400
H5	10,000	5	1900
H4	8,700	6	1500
H3	7,500	7	1200
H2	6,400	9	740
H1	5,400	10	370
1	4,500		
2	3,700		
3	3,000		

Weight and Volume of Douglas Fir and Southern Yellow Pine Poles

Pole Volumes (cubic feet)

Height	Pole Class H1	1	2	3
50	44.1	39.3	34.1	24.4
55	51.2	45.0	39.2	33.7
60	58.0	51.1	44.6	38.6
65	65.2	57.2	50.5	43.8
70	72.8	64.5	56.7	49.3
75	80.9	71.8	62.3	54.4
80	89.5	79.6	69.3	59.7
85	98.5	86.6	75.6	65.2
90	106.6	93.9	83.3	71.1
95	116.5	101.6	90.2	77.1
100	125.5	111.6	97.4	80.1

Pole Weights for Douglas Fir (treated)
(50 pcf assumed)

Height	Pole Class H1	1	2	3
50	2200	1970	1700	1220
55	2560	2250	1960	1690
60	2900	2560	2230	1930
65	3260	2860	2530	2190
70	3640	3225	2840	2470
75	4050	3590	3120	2720
80	4480	3980	3470	2990
85	4930	4330	3780	3260
90	5330	4700	4170	3560
95	5830	5080	4510	3860
100	6280	5580	4870	4000

Pole Weights of Southern Yellow Pine (treated)
(60 pcf assumed)

Height	Pole Class H1	1	2	3
50	2650	2360	2050	1470
55	3070	2700	2350	2020
60	3480	3070	2680	2320
65	3900	3430	3030	2630
70	4370	3870	3400	2960
75	4850	4300	3740	3260
80	5380	4780	4160	3580
85	5910	5200	4540	3910
90	6400	5630	5000	4270
95	6990	6100	5410	4630
100	7530	6700	5840	4800

APPENDIX G

CROSSARM DATA

Moment Capacities of Standard Crossarm Sizes

The following table gives moment capacities (M_{xx},M_{yy}) of standard size crossarms for transmission structures in REA Form 805. The moment capacities are based on the dressed size of the arms and a modulus of rupture of 7400 psi. M_{xx} is the moment resistance for vertical and M_{yy} is the moment resistance for longitudinal loads. Section moduli are also given for the respective axis.

Crossarm Size	S_{xx} cm^3 (in^3)	M_{xx} kN-m (ft-k)	S_{yy} cm^3 (in^3)	M_{yy} kN-m (ft-k)
3-5/8 x 9-3/8	818 (49.9)	41.7 (30.8)	310 (18.9)	15.8 (11.7)
(2)3-5/8 x 9-3/8	1640 (99.8)	83.5 (61.6)	619 (37.8)	31.6 (23.3)
3-5/8 x 5-5/8	289 (17.7)	14.8 (10.9)	184 (11.2)	9.4 (6.9)
(2)3-5/8 x 5-5/8	578 (35.3)	29.5 (21.8)	368 (22.5)	18.8 (13.9)
4-1/8 x 5-1/8	273 (16.7)	14.0 (10.3)	219 (13.3)	11.1 (8.2)
(2)4-1/8 x 5-1/8	546 (33.3)	27.9 (20.6)	437 (26.7)	22.3 (16.5)
4-5/8 x 5-5/8	372 (22.7)	19.0 (14.0)	304 (18.6)	15.5 (11.5)
(2)4-5/8 x 5-5/8	744 (45.4)	37.9 (28.0)	608 (37.1)	31.0 (22.9)
5-3/8 x 7-5/8	807 (49.2)	41.2 (30.4)	565 (34.5)	28.8 (21.2)
5-5/8 x 7-3/8	789 (48.2)	40.3 (29.7)	599 (36.6)	30.6 (22.5)

Example: Determine the maximum vertical span for a TSS-1L (69 kV)
Given : Conductor: 266.8 26/7 ACSR
Ldg. Dist: Heavy
Cond. Wt. (w_c): 1.0776 lbs/ft.
Insulator wt. (W_i): 51 lbs.
Moment arm(s): 5.5 ft.

Procedure: Moment capacity of TSS-1L arm (4-5/8" x 5-5/8") is 13.99 ft-k.

$$V.S. = \frac{M_a - (OLF)(W_i)(s)}{(OLF)(w_c)(s)}$$

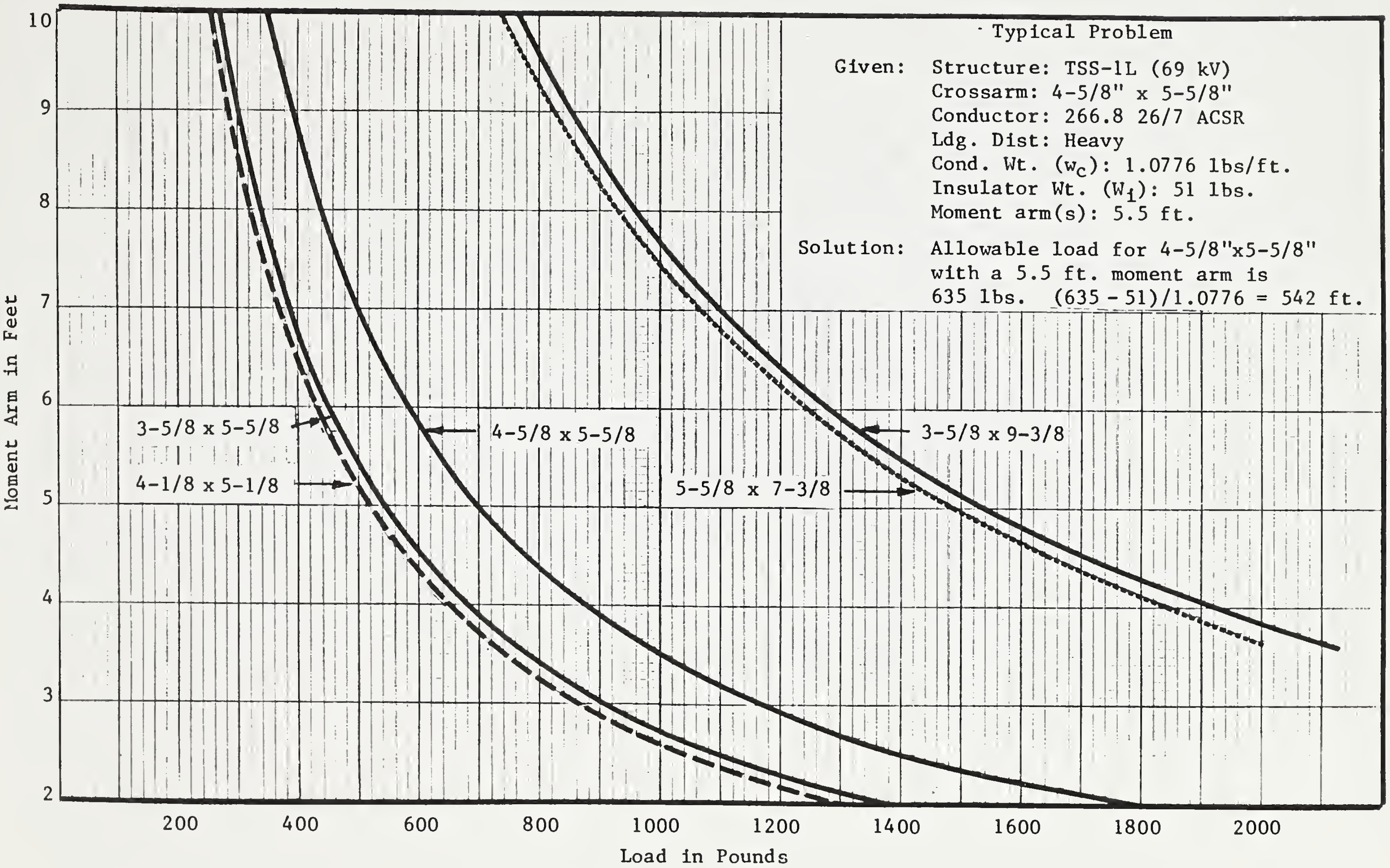
$$= \frac{13{,}990 - 4(51)(5.5)}{(4)(1.0776)(5.5)}$$

$$= 543 \text{ ft.}$$

CROSSARM LOADING CHART

Maximum Allowable Vertical Loads on Various Sizes of Douglas Fir Crossarms. A Fiber Stress of 7400/4 or 1850 is Assumed.

(For maximum ultimate vertical loads, multiply allowable loads by 4).



APPENDIX H

MISCELLANEOUS STRUCTURAL DATA

PROPERTIES OF COMMON SECTIONS

A = area (in^2, cm^2)

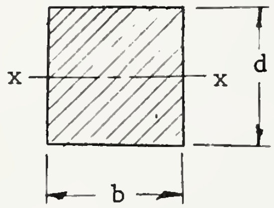
I_{y-y} = moment of inertia about the y-y axis

S_{y-y} = section modulus about the y-y axis

I_{x-x} = moment of inertia about the x-x axis (in^4, cm^4)

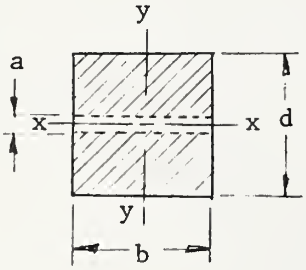
S_{x-x} = section modulus about the x-x axis (in^3, cm^3)

r_{x-x} = radius of gyration of x-x axis (in., cm)



$$A = bd \qquad S_{x-x} = \frac{bd^2}{6}$$

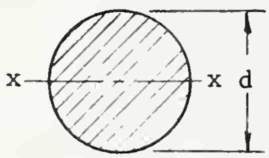
$$I_{x-x} = \frac{bd^3}{12} \qquad r_{x-x} = \frac{d}{\sqrt{12}}$$



$$A = b(d - a) \qquad r_{x-x} = \sqrt{\frac{d^2 + ad + a^2}{12}}$$

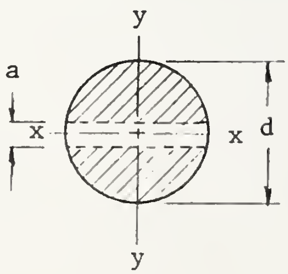
$$I_{x-x} = \frac{b(d^3 - a^3)}{12} \qquad I_{y-y} = \frac{(d - a)(b)^3}{12}$$

$$S_{x-x} = \frac{b(d^3 - a^3)}{6d} \qquad S_{y-y} = \frac{(d - a)(b)^2}{6}$$



$$A = \frac{\pi d^2}{4} = \pi R^2 \qquad S_{x-x} = \frac{\pi d^3}{32} = \frac{\pi R^3}{4}$$

$$I_{x-x} = \frac{\pi d^4}{64} = \frac{\pi R^4}{4} \qquad r = \frac{d}{4} = \frac{R}{2}$$

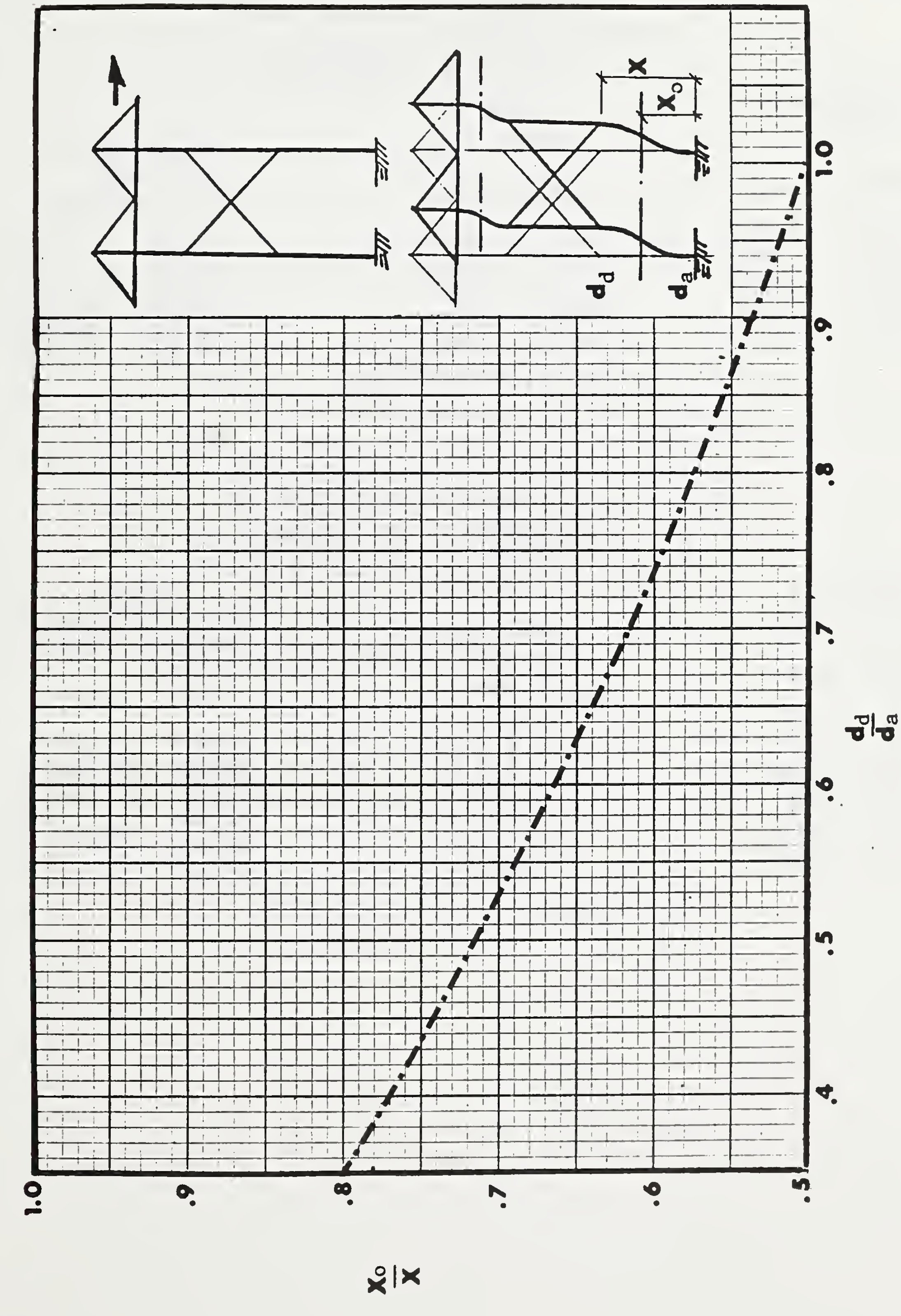


$$A = \frac{\pi d^2}{4} - da$$

$$I_{x-x} = \frac{\pi d^4}{64} - \frac{da^3}{12} \qquad I_{y-y} = \frac{\pi d^4}{64} - \frac{ad^3}{12}$$

$$S_{x-x} = \frac{\pi d^3}{32} - \frac{da^2}{6} \qquad S_{y-y} = \frac{\pi d^3}{32} - \frac{ad^2}{6}$$

Curve for Locating Plane of Contraflexure
in X-braced H-frame Structures



Strengths for Machine Bolts
Double Arming Bolts, Double End Bolts
Conforming to ANSI C135.1

Machine Bolt Diameter mm	(in.)	Tension Stress Area mm^2	$in.^2$	Min. Tensile Strength N	(lbs)
12.7	(1/2")	91.5	(.142)	34,700	(7,800)
15.8	(5/8")	145.8	(.226)	55,200	(12,400)
19.0	(3/4")	215.5	(.334)	81,600	(18,350)
22.2	(7/8")	298.1	(.462)	112,900	(25,400)
25.4	(1")	390.9	(.606)	149,000	(33,500)

Strength of Guy Strands

Strand Size mm	in.	Description	Minimum Breaking Strength N	(lbs)
9.53	(3/8")	H.S	48,000	(10,800)
7 No. 9 AWG		A.C.S	56,000	(12,600)
9.53	(3/8")	E.H.S	64,000	(14,400)
11.11	(7/16")	H.S	64,500	(14,500)
7 NO. 8 AWG		A.C.S	70,800	(15,930)
7 No. 7 AWG		A.C.S	84,800	(19,060)
11.11	(7/16")	E.H.S	89,300	(20,080)

APPENDIX I

RI AND TVI

SOME POSSIBLE SOURCES OF RI OR TVI ON TRANSMISSION LINES

(1) Poor contact between metal parts of suspension insulators - an insufficient vertical span or an uplift condition can cause this.

(2) Poor contact between clamp and clamp support bracket on clamp-top insulators.

(3) Loose conductor clamp.

(4) Loose hardware - can result from wood shrinkage or wind movement:

Crossarm braces or bolts;

Insulator mounting brackets.

(5) Loose staples, bonding wire or ground wire.

(6) Staples, bonding wire or ground wire too near ungrounded hardware.

(7) Bond or ground wire clamped against wood under washer.

(8) Unbonded guy wires too close to each other or to pole hardware.

(9) Slack guy wire causing poor contact at pole attachments or at anchor eye.

(10) Metal-to-metal clearance insufficient on pole hardware.

(11) "Trash" on conductors (bits of wire, metal kite strings, tree limb, etc.).

FORMULAE FOR CALCULATING SURFACE GRADIENTS OF CONDUCTORS

Excessively High Conductor Surface Gradients Can Result In Radio Noise, Television Interference, And Corona. The equations below can be used to check the surface gradient. They are approximate but yield reasonably accurate results. They assume phase conductors that are far apart compared to their diameter.

A. Equation for Single Conductor per Phase

$$g = \frac{kV_{LL}}{\sqrt{3}r \ln \frac{D}{r}} \qquad \text{(Eq. I-1)}$$

where:

kV_{LL} is the line-to-line voltage, in kV
r is the conductor radius, in cm.
D is the geometric mean distance (GMD) of the phase conductors, in cm.
g is the conductor surface gradient, in kV/cm.

B. Equation for Two Conductor Bundle per Phase

$$g = \frac{kV_{LL}(1+2\ r/s)}{2\sqrt{3}\ r \ln \frac{D}{\sqrt{rs}}} \qquad \text{(Eq. I-2)}$$

where all the symbols are the same as those above with the addition that:

s is the separation between subconductors, in cm.

C. Application of Formulae: It is recommended that transmission line designs that have unusually close phase spacing have the conductor surface gradient checked. A maximum conductor gradient of 16 kV/cm should be used.

D. Example: Determine the conductor gradient for a 230 kV line with (1) a 556.5 kcmil (dove) ACSR conductor and (2) a 1272 kcmil (pheasant) conductor. GMD for TH-230 is 24.57 feet or 748.90 cm.

1. 556.5 kcmil conductor

$$r = \frac{.927}{2}(2.54) = 1.18$$

$$g = \frac{230(1.05)}{\sqrt{3}(1.18) \ln \frac{748.90}{1.18}}$$

$g = 18.3$ kV/cm.

2. 1272 kcmil conductor (1 conductor)

$$r = \frac{1.382}{2}(2.54) = 1.755$$

$$g = \frac{230(1.05)}{\sqrt{3}(1.755) \ln \frac{748.90}{1.755}}$$

$g = 13.12$ kV/cm.

APPENDIX J

(For future use)

APPENDIX K

SYMBOLS AND ABBREVIATIONS

SYMBOLS AND ABBREVIATIONS

A =	Cross sectional area.	m^2, mm^2 or ft^2, in^2
A =	Separation between points of suspension of insulator string for two phases.	m, ft. m, ft.
A =	Allowable separation at midspan.	m, ft.
A_u =	Designated ultimate anchor capacity.	N, lbs.
B =	Vertical separation at supports.	m, ft.
C =	Clearance between a supply conductor and an object or ground. May be specified as C_1, C_2, C_3, etc.	m, mm or ft., in.
C =	Circumference of a pole. Depending on the location, the circumference may be indicated as C_A, C_B, C_C, etc.	cm, in.
D_e =	Embedment depth.	m, ft.
D_v =	Vertical separation between conductors.	m, ft.
E_c =	Experience factor for horizontal separation requirements. It is generally recommended that E be greater than 1.25.	
E =	Modulus of elasticity of wood.	Pa, psi
F =	Wind pressure on a cylindrical surface.	Pa, psi
F_b =	Designated ultimate bending stress for either the pole or the crossarm.	Pa, psi
F_c =	Experience factor to be used in horizontal separation requirements (F_c = 1.15 for light loading district, 1.2 for medium loading district, and 1.25 for heavy loading district).	
F_s =	Designated ultimate skin friction of soil.	Pa, psf
G, G_N =	Calculated force in the guy, considering guy lead.	N, lbs.
G_u =	Rated breaking strength of guy.	N, lbs.
H =	Horizontal separation between the phase conductors at the structure.	m, ft.

HS	= Horizontal span. For any structure, the $HS = (L_1 + L_2)/2$ and is the horizontal distance between the midspan points of adjacent spans. The horizontal span times the wind force per foot on the conductor (p_c) will yield the total horizontal force per conductor on the structure.	m, ft.
HS_N	= For an H-frame structure, HS_A, HS_B, etc., are the horizontal spans limited by pole strength at the various locations on the pole.	m, ft.
HS_R	= Horizontal span limited by uplift or bearing.	m, ft.
HS_X	= Horizontal span as limited by crossbrace strength of an H-frame structure.	m, ft.
I	= Moment of inertia of a structural member.	cm^4, in^4
L	= Total length of a pole.	
L	= Span length or the horizontal distance from one structure to an adjacent structure. L_1, L_2, L_3, etc. are designations for different spans.	m, ft.
L_{avg}	= Average span length.	m, ft.
L_{max}	= Maximum span.	m, ft.
LL	= Loop length of conductor when vibrating.	m, ft.
M	= Major axis of Lissagous ellipses.	m, ft.
M_a	= Moment capacity of crossarm.	N-m, ft-lbs.
M_g	= Moment capacity of a pole at groundline.	N-m, ft-lbs.
M_N	= Moment capacity at the indicated location.	N-m, ft-lbs.
M_{bh}	= Moment capacity reduction due to a bolt hole.	N-m, ft-lbs.
M_{wp}	= Moment due to wind on the pole.	N-m, ft-lbs.
M_{vo}	= Moment due to unbalanced vertical load	N-m, ft-lbs.
M_{wc}	= Moment due to wind on the conductor.	N-m, ft-lbs.
$M_p\text{-}\delta$	= Moment due to deflection of the structure (from wind load) and resulting movement of the vertical load.	N-m, ft-lbs.

OCF	= Overload capacity factor.	N-m, ft-lbs.
P	= Horizontal force.	N, lbs.
P_c	= Force due to wind on conductors (plus ice, if any).	N, lbs.
P_g	= Force due to wind on OHGW (plus ice, if any).	N, lbs.
P_t	= Force due to wind on conductors and OHGW (plus ice, if any).	N, lbs.
P_{cr}	= Critical buckling load for a member in compression.	N, lbs.
R	= Rise of a davit arm.	
R	= Total transverse load due to wind on the conductors and OHGW and wire tension load for conductors and OHGW.	N, lbs.
R_c	= Total transverse load due to wind on the conductors (P_c) and wire tension load for conductors (T_c).	N, lbs.
R_g	= Total transverse load due to wind on the OHGW (P_g) and wire tension load for OHGW (T_g).	N, lbs.
RS	= Ruling span.	m, ft.
S	= Section modulus of a structural member equal to I/c.	cm^3, in^3
S	= Sag of conductor.	
S_e	= Soil constant.	
S_f	= Final sag of a bare conductor at condition specified.	m, ft.
S_i	= Sag of an iced conductor.	m, ft.
S_ℓ	= Sag of the lower bare conductor.	m, ft.
$S_{i\ell}$	= Sag of an iced lower conductor.	m, ft.
S_{RS}	= Sag at midspan for a span equal to the ruling span.	m, ft.
S_u	= Sag of an upper conductor.	m, ft.

S_{iu}	= Sag of an iced upper conductor.	m, ft.
SP	= Diagonal distance between phase conductors at structure.	m, ft.
T	= Resultant tension at support.	N. lbs.
T_c	= Average conductor tension	N, lbs.
T_g	= Average OHGW tension.	N, lbs.
T_h	= Horizontal component of tension.	N, lbs.
T_{avg}	= Average conductor tension in a span ($T_{avg} = \frac{T_h + T}{2}$).	N, lbs.
V	= Wind velocity.	km/hr, miles/hr
V	= Vertical separation between phase conductors at a structure.	m, ft.
VS	= Vertical span, the horizontal distance between the maximum sag points of two adjacent spans. The vertical span times the weight of the loaded conductor per foot (w_c) will yield the vertical force per conductor bearing down on the structure.	
W	= Weight.	N, lbs.
W	= Right-of-way width.	m, ft.
W_c	= Weight of conductors (plus ice, if any).	N, lbs.
W_g	= Weight of OHGW (plus ice, if any).	N, lbs.
W_p	= Weight of pole.	
W_i	= Weight of insulators.	N, lbs.

a	= Length as indicated.	m, ft.
a	= Insulator swing clearance for normal condition.	mm, in.
b	= Distance between two poles for an H-frame structure.	m, ft.
b	= Bolt hole diameter; width of a section.	mm, in.
b	= Insulator swing clearance for 6 psf wind condition.	mm, in.
c	= Insulator swing clearance for high wind condition.	mm, in.
c	= Distance from the neutral axis to the extreme fiber.	cm, in.
d_c	= Diameter of conductor.	mm, cm, in.
d_g	= Diameter of overhead ground wire.	cm, in.
d_g	= Diameter at the groundline of a pole.	cm, in.
d_n	= Diameter of a pole. Depending on the location the diameter may be indicated as d_a, d_b, d_c, d_d, etc.	cm, in.
d_t	= Diameter at the top of a pole.	cm, in.
f	= Frequency of conductor vibration.	Hz
f_b	= Computed bending stress.	Pa, psi
f_s	= Computed skin friction of soil.	Pa, psf
g	= Acceleration due to gravity 9.81 (32.2).	m/sec^2, ft/sec^2
g	= Conductor surface gradient.	
h_n	= Length, May be indicated as h_1, h_2, h_3, or h_a, h_b, h_c, etc..	m, ft.
kV_{LG}	= Line to ground voltage.	kV
kV_{LL}	= Line to line voltage.	kV
ℓ	= Unbraced length used in buckling calculations.	m, ft.
ℓ_i	= Insulator string length.	mm, m or in, ft.

m_c =	Mass per unit length of the conductor.	kg/m, lb_m/ft.
m_g =	Mass for unit length of the overhead ground wire.	kg/m, lb_m/ft.
p_c =	Horizontal force per unit length due to wind on the conductors (plus ice, if any).	N/m, lbs/ft.
p_g =	Horizontal force per unit length due to wind on the overhead ground wire (plus ice, if any).	N/m, lbs/ft.
p_t =	Total horizontal force per unit length due to wind on the conductors and overhead ground wire.	N/m, lbs/ft.
q_a =	Calculated allowable soil bearing capacity.	Pa, psf
q_u =	Calculated ultimate soil bearing capacity.	Pa, psf
r =	Radius of gyration. A property of a cross section equal to $\sqrt{I/A}$.	mm, in.
r =	Radius of conductor.	mm, in.
r_c =	Resultant load per unit length on conductor including ice and wind and K factor.	N/m, lbs/ft.
s =	Maximum moment arm for a crossarm.	m, ft.
s_n =	Moment arm for crossarm; "s_a,s_b,s_c" for phase conductors, "s_g" for ohgw, "s" as shown on the drawing.	m, ft.
w_c =	Weight per unit length of the conductors (plus ice, if any).	N/m, lbs/ft.
w_g =	Weight per unit length of the overhead ground wire (plus ice, if any).	N/m, lbs/ft.
w_t =	Total unit weight per unit length of all wires combined	N/m, lbs/ft.
x_n,y_n,z_n =	Length. May be indicated as x_0, x_1, z_0, z_1, etc.	m, ft.

α =	Linear coefficient of expansion per degree C (degree F).	m/deg, ft/deg
β =	Angle which the guy makes with the groundline.	deg.
δ =	Structure deflection.	mm, m or in., ft.
ϕ =	Guy angle with ground.	deg.
ϕ =	Insulator swing angle.	deg.
ϕ_{max} =	Maximum insulator swing angle.	deg.
θ =	Line angle.	deg.

δ_{imp} - Deflection.

δ_{mag} - Deflection magnifier.

APPENDIX L

SELECTED SI-METRIC CONVERSIONS

Selected SI-Metric Conversions

AREA

To Convert From	To	Multiply by	
circular mil (cmil)	square meter (m^2)	5.067075	E-10
square centimeter (cm^2)	square meter (m^2)	*1.000	E-04
square foot (ft^2)	square meter (m^2)	*9.290304	E-02
square inch (in^2)	square meter (m^2)	*6.451600	E-04
square kilometer (km^2)	square meter (m^2)	*1.000	E+06
square mile (mi^2)	square meter (m^2)	2.589988	E+06

FORCE

To Convert From	To	Multiply by	
kilogram force (kgf)	newton (N)	*9.806650	
kip	newton (N)	4.448222	E+03
pound force (lbf)	newton (N)	4.448222	

FORCE PER LENGTH

To Convert From	To	Multiply by	
kilogram force per meter (kgf/m)	newton per meter (N/m)	*9.806650	
pound per foot (lb/ft)	newton per meter (N/m)	1.459390	E+01

DENSITY

To Convert From	To	Multiply by	
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767990	E+04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601846	E+01

LENGTH

To Convert From	To	Multiply by	
foot (ft)	meter (m)	3.048	E-01
inch (in)	meter (m)	*2.540	E-02
kilometer (km)	meter (m)	*1.000	E+03
mile (mi)	meter (m)	*1.609344	E+03

*Exact Conversion.

Selected SI-Metric Conversions, cont.

LINEAR DENSITY

To Convert From	To	Multiply by	
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488164	
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785797	E+01

LOAD CONCENTRATION

To Convert From	To	Multiply by	
pound per square inch (lb/in^2)	kilogram per square meter (kg/m^2)	7.030696	E+02
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882428	
ton per square foot (ton/ft^2)	kilogram per square meter (kg/m^2)	9.071847	E+02

MASS

To Convert From	To	Multiply by	
pound (avoirdupois)(lb)	kilogram (kg)	4.535924	E-01

PRESSURE

To Convert From	To	Multiply by	
kip per square inch (kip/in^2)	pascal (Pa)	6.894757	E+06
kip per square foot (kip/ft^2)	pascal (Pa)	4.788026	E+04
newton per square meter (N/m^2)	pascal (Pa)	*1.000	
pound per square foot (lb/ft^2)	pascal (Pa)	4.788026	E+01
pound per square inch (lb/in^2)	pascal (Pa)	6.894757	E+03

BENDING MOMENT

To Convert From	To	Multiply by	
kilogram force meter (kgf-m)	newton meter (N-m)	*9.806650	
kip-foot (kip-ft)	newton meter (N-m)	1.355818	E+02
pound-foot (lb-ft)	newton meter (N-m)	1.355818	

*Exact Conversion.

Selected SI-Metric Conversions, cont.

VELOCITY

To Convert From	To	Multiply by	
foot per second (ft/s)	meter per second (m/s)	*3.048	E-01
kilometer per hour (km/h)	meter per second (m/s)	2.777778	E-01
mile per hour (mi/h)	meter per second (m/s)	4.470400	E-01
meter per hour (m/h)	meter per second (m/s)	2.777778	E-04

VOLUME

To Convert From	To	Multiply by	
cubic foot (ft^3)	cubic meter (m^3)	2.831685	E-02
cubic inch (in^3)	cubic meter (m^3)	1.638706	E-05
cubic kilometer (km^3)	cubic meter (m^3)	*1.000	E+09
cubic millimeter (mm^3)	cubic meter (m^3)	*1.000	E-09

TEMPERATURE

	Degrees Celcius ^oC	Degrees Fahrenheit ^oF
X^oC =	----	$\frac{9}{5}X + 32$
X^oF =	$\frac{5}{9}(X - 32)$	----

*Exact Conversion.